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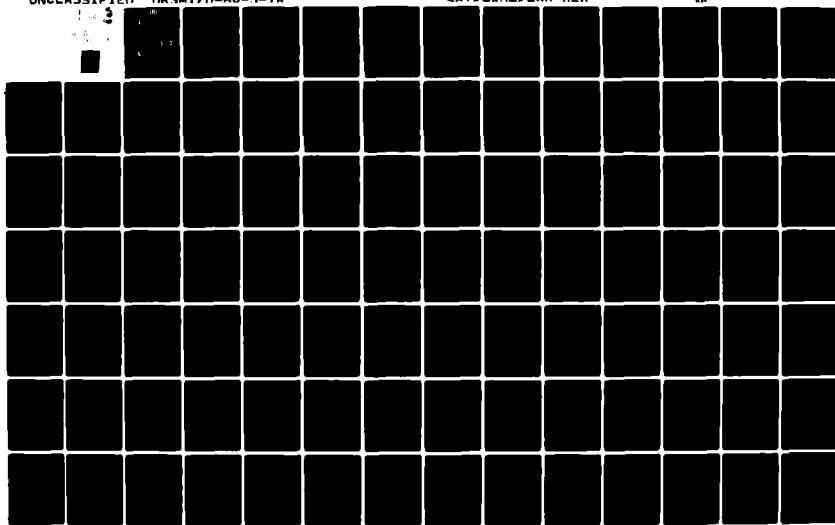
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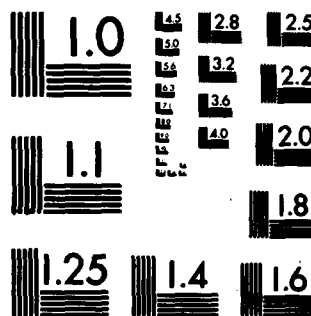
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Technical Report D-80-5

A HEURISTIC ROUTE SELECTION MODEL FOR LOW LEVEL
AIRCRAFT FLIGHT THROUGH DEFENDED TERRAIN

Michael James Dorsett
Plans, Analysis, and Evaluation Directorate
US Army Missile Command

MAY 1980

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U.S. ARMY MISSILE COMMAND

Redstone Arsenal, Alabama 35809

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents a heuristic route selection model for developing aircraft routes through hostile terrain. The capability of modern air defense systems has forced aircraft to utilize low level flight to avoid detection, thereby increasing survivability. By identifying the high and low points within an area, the model determines their exposure values, which are utilized with their height and internode distance to calculate a penalty for flying to a point from the current position. In developing a route, the model utilizes basic		

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information concerning air defense deployment, initial and destination points, and terrain data to specify a minimum-exposure, minimum-elevation route.

The results include the development of routes for eight 10 by 10 kilometer areas, and six larger terrain areas varying in size from 20 by 20 kilometers to 35 by 35 kilometers. Validation shows the heuristic to be competitive with visual procedures, but at a large reduction in time.

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CHAPTER I

INTRODUCTION

1.1 Background

Throughout history man has engaged in battle with his fellow man. A review of history is a review of warfare. Man seems to have a general propensity to consider warfare a major objective in his life. The early settlers of this country encountered a formidable foe in the native Americans. The covered wagon caravans were the early settlers' attempts to minimize the Indian threat when traveling West. Further, the scouts would seek high vantage points in the terrain where they could observe and provide early warning of enemy forces and their movement.

Scientific and technological developments have provided present day man with complex equipment and devices with which to do battle with his enemies. Commonplace among this arsenal are missiles, high performance aircraft, helicopters, air defense systems, tanks, radars, submarines, and a host of sophisticated hand-held weapons including lasers. It should be noted that the radar replaces the observer on the lonely hill top, while tanks and armoured vehicles replace the covered wagons. The major difference in the two scenarios is the equipment of which aircraft, missiles and air defense systems are of concern in this research effort. It is with the concept of air defense that modeling becomes paramount, since models permit reality to be depicted for a very modest investment of time and money.

1.2 Air Defense Modeling

The effectiveness of medium and high air defense systems impose a high degree of risk to aircraft survivability when an aircraft is operating in the air space protected by these systems. This situation leaves low level flight as the only option open to the aircraft to avoid these air defenses. Aircraft are a high value resource which must be utilized wisely. Regardless of the results of the analysis, the mission has to be undertaken. The battle, and in turn the war, can only be won if one attacks. Thus, one must enhance the aircraft's probability of survival.

One means to increase the aircraft's chances of survival is to plan a route which minimizes its exposure to enemy air defenses. A terrain following route can be optimized in the vertical plane, but the initial question is where to position the ground track in the horizontal plane that the aircraft will follow. If one knew the route which minimized the exposure, then there would be an easing of the vertical constraint imposed by the air defenses [1].

The objective of this research is to develop a heuristic method for selecting a minimum-exposure, minimum-elevation route for terrain following flight through defended terrain. Considering the expensive aircraft in use today, the computer modeling of air operations on the tactical battlefield is a useful tool for assessing tactics, performance, and results.

1.3 Research Topic

If one knew the location of low exposure routes, then an assessment could be made on the expected outcome of employing these routes. The high exposure route is merely to allow the aircraft to fly within the

radar coverage. This research was undertaken to find a method which allows one to find the low exposure route from some initial point to a destination point.

A minimum exposure route will logically use terrain features to hide the aircraft from the air defense sensors. This assumption implies that low elevation areas should have a lower exposure profile than high elevation areas. It is intended to use the low elevation areas as the basic units from which a minimum exposure route can be built. Thus, a heuristic route selection model will be developed in this dissertation that achieves a minimum-exposure, minimum-elevation route for low level flight.

1.4 Outline of Succeeding Chapters

Chapter II is a review of the literature pertaining to routing, aircraft and air defense. Three documents of particular interest to this research are discussed first. The remainder of the chapter pertains to the literature in general. The tactical situation from which this research derives is given in Chapter III. The scenario is typical of a medium intensity battle. The development of the model is presented in Chapter IV. The discussion follows the solution sequence of the model.

Chapter V is an example of the model selecting an appropriate route for the prescribed conditions. The calculations are based on the material of Chapter IV. The model results are contained in Chapter VI. The results for two small terrain areas are presented first, followed by the results for a much larger terrain area.

Chapter VII is the validation of the developed model. Some of the model results are compared to manually developed, preferred routes. Finally, Chapter VIII presents the conclusions of this research and recommendations for further research.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

An intensive review of the literature identifies three research results which are pertinent to this effort. A recent dissertation by James E. Funk [2] provides a method for determining the optimal vertical flight path for a given route. The second effort was reported in The University of Alabama in Huntsville Research Institute (UARI) Report, Optimal Attack Route Selection Method [3]. The third research of interest is a Helicopter Route Selection Model developed by Ohio State University for the large land combat model DYN TACS [4]. In addition, the literature pertaining to network modeling, computer software algorithms, geology and geography, highway routing, and electronic circuit routing were investigated to determine their applicability in aircraft routing.

Modern air defense systems have the capability to deny medium or high altitude aircraft attack routes to a target. To overcome this restriction, low level flight has now become a preferred method for penetrating air defenses. Low level or terrain following flight paths, however, presents the problem of impact with the terrain. In the literature this problem is also referred to as clobber.

The ideal flight path for terrain following would be a flight curve that matches the terrain curvature by some clearance height above the local terrain. The aircraft control system limits the vehicle to flying a smooth flight path which approximates this clearance curve. Figure 2.1

is an illustration of a typical terrain profile with the clearance curve and flight path for low level flight. The slower the aircraft flies the closer the flight path can approximate the clearance curve.

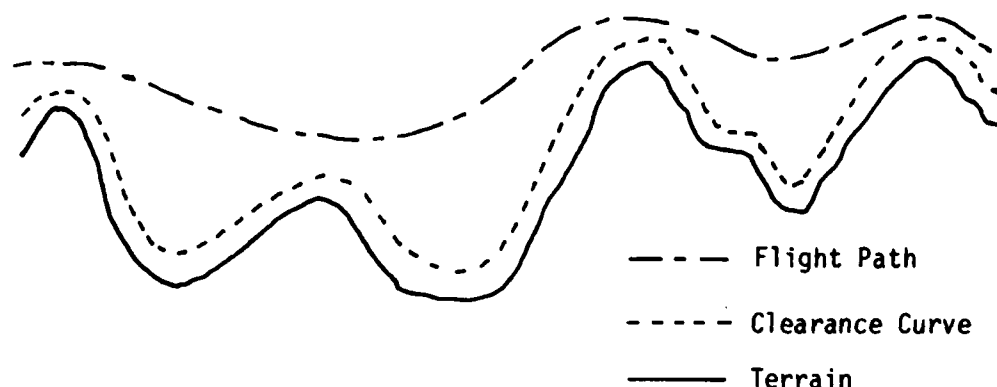


Figure 2.1. Low Level Flight Profile.

The review of unclassified documents concerning low level flight has centered on the problem of optimal aircraft control systems. Advances in microprocessors and digital electronics seem to be the controlling factor in increasing the capability of on-board flight computers and navigation systems [2, 5, 6]. With increased on-board computer capacity, real time optimization of flight profiles become possible, thereby achieving an optimal low level flight path along the selected route.

In the literature that was reviewed, a major consideration in any air defense study is terrain modeling. Terrain modeling is also utilized in such studies as highway routing and construction, pipeline routing, and land use. Most recent research in this area is directed at using computer graphics to depict the terrain in contour map form and in picture form. Existing terrain models are presently adequate for air defense modeling [7, 8, 9, 10, 11]. The terrain models, however, do not provide for aircraft route selection analysis.

2.2 Reported Research

The dissertation by J. E. Funk presents a mathematical programming method for solving the aircraft control problem in terrain following flight [2]. The first step in his approach was to construct a trajectory model which is incorporated into the objective function or, as he has defined it, the performance function. The performance function is defined in terms of an excess clearance variable. The function is optimized subject to differential constraints of height, slope and curvature of the flight path.

To provide computational ease the problem is discretized. The performance function and constraints are transformed to a matrix form which can now be considered as a quadratic or linear programming (LP) problem. This quadratic or LP problem is solved using existing algorithms. To develop a complete flight path this procedure considers overlapping segments. Segment i of the flight path is optimized and then the next overlapping segment, $i+1$, is optimized with the initial portion of segment $i+1$ defined by segment i . Since the discrete segments overlap, the resulting flight path is continuous and there are no discontinuities at the boundaries.

In Funk's research, only the vertical terrain avoidance is examined, and not the lateral terrain avoidance. His results give a solution to the aircraft control system to yield the optimal flight path over a given terrain route.

In the UARI report, a dynamic programming approach for determining optimal attack routes is presented [3]. Although this work was performed several years ago, it is still current with techniques recently reported. The backwards solution method was employed to evaluate the recursive function.

The route selection process that was developed is a direct application of dynamic programming. To represent the multi-stage decision process, a grid network was used where each grid point is equivalent to a stage in the decision process. Thus, the optimal decision path is the optimal attack route.

The probability of survival, (P_s), is the return at each stage. The optimal path has the highest probability of survival or is the least risk route. The probability of survival at a grid point is given by:

$$P_s = (1 - P_k).$$

The probability of kill (P_k) for an air defense site is the resultant of the probabilities of acquisition, tracking, missile launch, missile flight, and warhead lethality.

Two recommendations for further research in this report were of interest. This technique had only been applied to small scale problems, and further research on large scale problems with multi-attackers and multi-radar sensors were suggestions for consideration. Also, it was recommended that network techniques such as shortest path or least cost path be considered.

The Helicopter Route Selection Model that has been developed is another method using dynamic programming [4]. This model is an adaptation of the ground unit route selection model that is a subroutine of DYN-TACS X. The first step is to determine the intervisibility areas for each weapon. These areas define the masked and unmasked portions of the battlefield. From the set of masked areas a series of concealed areas in close proximity to one another can be connected to form an avenue of approach. Having identified this avenue the route can be selected that follows the general shape of the approach corridor.

Up to this point all analyses of intervisibility and terrain have been performed outside of the actual model. With the process completed the route corridor is defined in the model. The intervisibility areas are defined by a set of irregular convex shapes having straight line boundaries between each vertex. Along each boundary one or more points define the possible beginning (or end) of a route segment across the convex shapes (Figure 2.2). These points are shown as circles on Figure 2.2 and are also entered into the model as data.

With the terrain area thus described for the model, the route selection routine can be utilized. A series of nine points that are in the direction of attack are selected for route analysis. The selection routine evaluates these boundary points identified by the probability of survival at each point. The point with the highest probability of survival is selected and then the next series of nine points along the route corridor are considered. This process is the forward solution method for dynamic programming problems.

2.3 Open Literature

One of the first areas in the open literature to be investigated was cluster analysis. An excellent presentation of cluster analysis can be found in Anderberg's text [12]. When data has no discernible pattern, cluster analysis can provide a tool to uncover the pattern. Hierarchical clustering is widely utilized to develop the linking of data as each entity is processed. In this research, the idea of nearest neighbor and centroid of a cluster that is used with non-hierarchical clustering, are utilized as a basis for processing the terrain data.

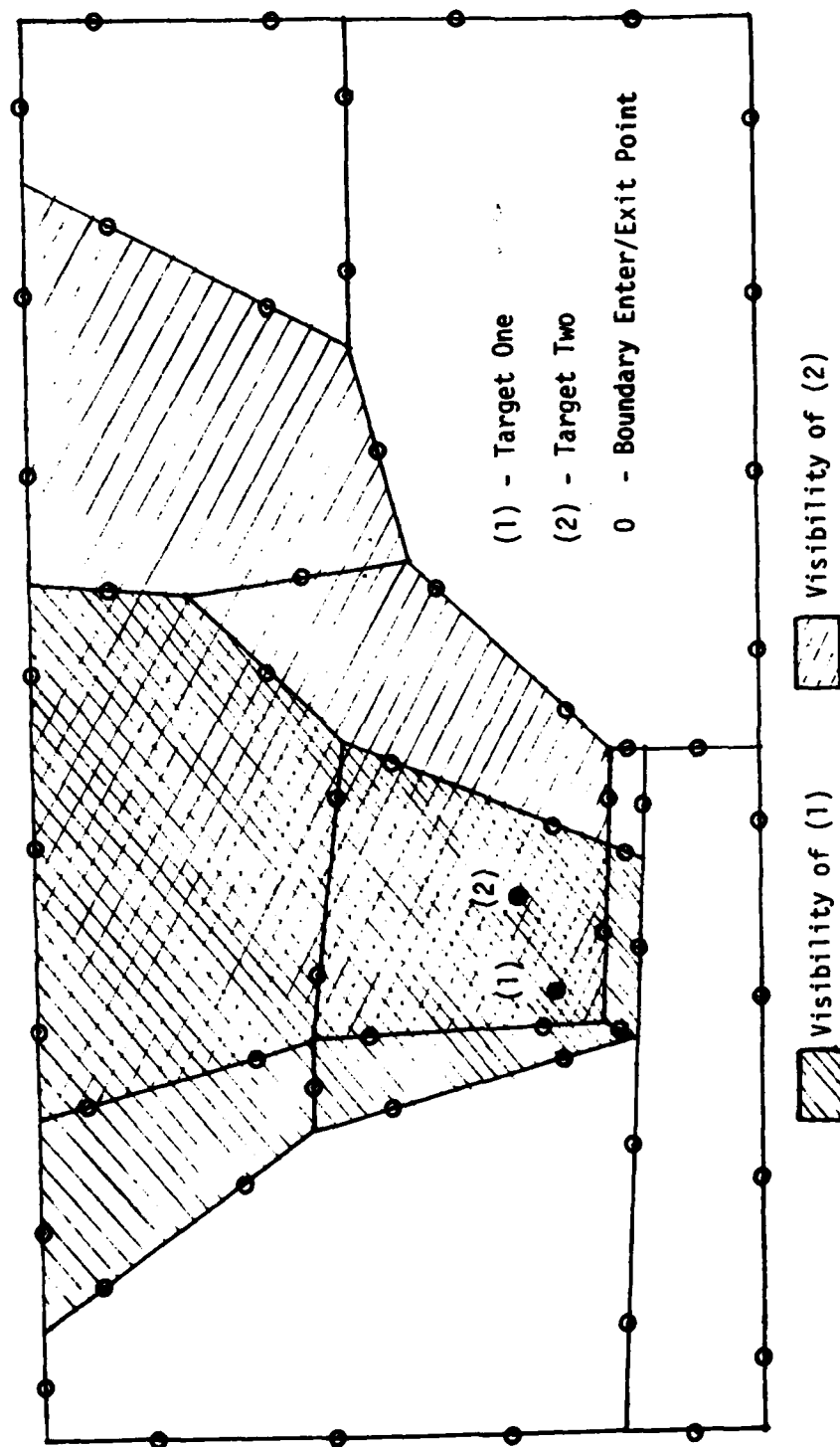


Figure 2.2. Partitioned Terrain Area.

For a data set of N observations, clustering into subsets of like values indicates an association or similarity for the cluster membership which is not shared by those outside that cluster. Typically, the members of a cluster will minimize some criterion such as minimal distance from the mean of the cluster. The mean of a cluster can be utilized as the centroid. For the total data set of k clusters, membership in cluster i can have a point to centroid distance different from cluster j , which would indicate an individual cluster density. Thus, a higher order clustering can be performed on the initial clusters because their centroids are now the data points. The centroids of the first order cluster can be weighted according to density and be the point used as the value for the higher order clustering.

Clustering methods are means by which data can be grouped, associated, or placed in some classification scheme for analysis. There is no one preferred method to be used, as several methods normally need to be used to determine if there is any pattern or intelligence to be derived from the data.

The aircraft routing problem can be formulated as a network or a graph problem. In the literature, the theoretical aspects of a network are referred to as graph theory, whereas the practical aspects are known as network analysis. A highway network connecting cities would be vertices for the cities and edges for the highways when related to graph theory. Networking would refer to the cities as nodes and the highways as arcs. Depending on the reference, the terminology for the cities could also be called junction points, intersection points, or simply points; and likewise, an arc could also be a branch, link, path or line.

For a network or graph G there is a collection of points x_1, x_2, \dots, x_n (denoted by the set X), and a collection of lines a_1, a_2, \dots, a_m (denoted by the set A) which join some or all of these points. The graph is described and denoted by the doublet $G(X, A)$ [13]. An edge joining x_i with x_j is denoted by $[x_i, x_j]$.

In network analysis and cluster analysis there are three distance measures that are of interest. First, the standard Euclidean distance or metric for two points in space is given by:

$$d = \left[(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2 \right]^{1/2}.$$

Second, in many location problems, especially in urban areas, travel is along an orthogonal set of streets. Travel which is restricted to directions parallel to the coordinate axes use a rectilinear or Manhattan metric that defines distance between two points (x_1, y_1) and (x_2, y_2) by:

$$|x_1 - x_2| + |y_1 - y_2|.$$

The rectilinear metric could have been used in the UARI Optimal Attack Route Method since travel was restricted to grid lines. Third, when travel is restricted to take place on a network, then the internode lengths are the distance measure [14].

The above concepts were utilized in developing the approach to the route selection process for low flying aircraft. The ideas of nearest-neighbor and cluster centroid form the bases for the terrain data reduction.

CHAPTER III

PROBLEM FORMULATION

3.1 Tactical Scenario

This research considers an area of air defense war gaming. There are two basic situations that a tactician can analyze. In one case, the tactical situation is portrayed from the defender or air defense site aspect. For the other case, the tactical situation is presented from the attacker or pilot's viewpoint. The specific problem this research addresses is that of selecting a route which a low flying aircraft can use to penetrate the air defense coverage, while at the same time minimizing the aircraft exposure to these defenses. *Low flying* aircraft ordinarily fly within 200 meters of the terrain.

The defender desires to allocate his air defenses in a pattern to achieve maximum coverage. The sensors (radar, infrared, or visual) are positioned in the terrain to be defended such that visibility is maximum in the principle direction the site is responsible for protecting. In actual terrain there can be certain azimuths for which coverage is marginal or non-existent. To ensure that the total area is covered, the air defense sites are situated so that individual site visibilities overlap each other thereby providing a pattern with total coverage. Thus, any portion of the total area is being covered by one or more air defense sites. The attacker is faced with the situation of attempting to select a route which avoids these sites and maximizes his survival while reaching the target, and accomplishing the mission.

Along with terrain following, there are some other options the tactician can choose to enhance the aircraft and pilot's survivability. The attacker can use electronic countermeasures (ECM), better known as jamming. An anti-radiation missile (ARM) could be fired at each radar. Decoys or remotely piloted vehicles (RPV's) could be utilized to saturate the skies so that an aircraft can be hidden among the RPV's. To reach the primary target, a preemptive raid could be made against the air defenses. Of course, the defender is fully aware of these and other methods that can be employed to negate the air defense's ability to engage the attackers.

3.2 Aircraft Route Selection

In this research, the air defense situation is a heavily defended 35 by 35 km area through which a helicopter force must penetrate. The air defense sensors are assumed to be deployed within this region such that maximum coverage exists.

Using military terminology, the line of battle between two forces is known as the forward edge of the battle area (FEBA). The helicopter force is flying a terrain following flight path from their base across FEBA to raid an enemy rear area base. The enemy air defense sensor capability is assumed to have good low altitude coverage for a 10 km radius and good long range coverage for medium and high altitude.

In performing this raid, the objective is to traverse the whole route undetected, thus preserving the element of surprise in the attack. The air defense sensors are not being attacked or jammed in this raid. In an attempt to obscure the helicopters' approach to the target, the mountains and hills would be utilized as a mask. Intuitively, the best low level aircraft route would follow the lowest terrain. To offset this

tactic, the enemy will position some air defense sites to cover low altitude corridors into his area.

The interaction of these tactics results in the helicopter route selection being that of finding the low level route which has the fewest air defense sites covering it. Thus, a route is a linkage of several low level path legs into a continuous path that will allow the aircraft to avoid detection.

3.3 Sensor Coverage

With low altitude targets, radar sensors have clutter problems when receiving the return signal. There can be a high level of noise because of ground objects and terrain features which tend to obscure any targets that may be nearby. Any aircraft operating in an area with opposing air defenses will attempt to fly as low as possible so as to be in the clutter of the radar return signal. However, the faster the aircraft speed the higher it must fly to be responsive to the pilot's terrain avoidance commands. Thus, the aircraft pilot has two conflicting constraints; first, the aircraft must fly no higher than X meters to avoid detection, yet, second, it must fly at least Y meters above the terrain to maintain a clearance altitude. A major problem exists for the pilot when Y is greater than X .

The degree of coverage a radar site possesses from a given location is dependent on the target altitude and the local terrain. An aircraft at 50 meters altitude is more likely to be detected than an aircraft at 20 meters altitude. To graphically illustrate sensor visibility, a series of actual coverage diagrams for three sites were made at target altitudes of 20 and 50 meters. Penetrating aircraft are assumed to be approaching the sites from the west (left edge of figures). Coverage diagrams are

generated using a computer routine that generates the visibility from a site to the target altitude for 0 to 360 degrees in azimuth.

The first site, Figure 3.1, has excellent coverage to the west at each altitude. For increasing target altitudes only a small improvement in visibility is obtained. Visibility for a 10 km radius at 20 meters target altitude is 28.02 percent of the total area. At 50 meters, visibility is 31.85 percent.

In Figures 3.2 and 3.3, the site has good coverage at each altitude. At 20 meters target altitude, visibility is 29.85 percent and improves to 43.10 percent at 50 meters. The prominent direction of coverage is west, but this site also has some coverage to the east.

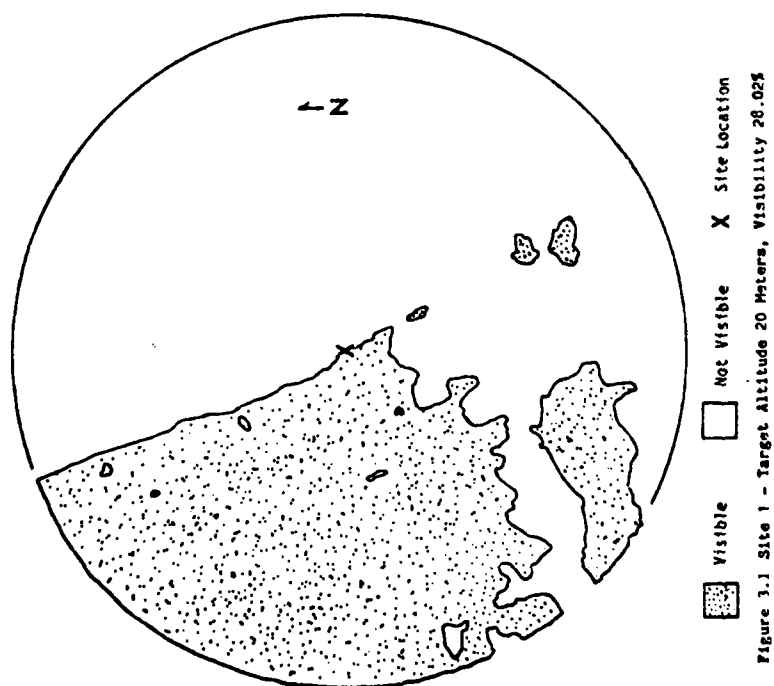
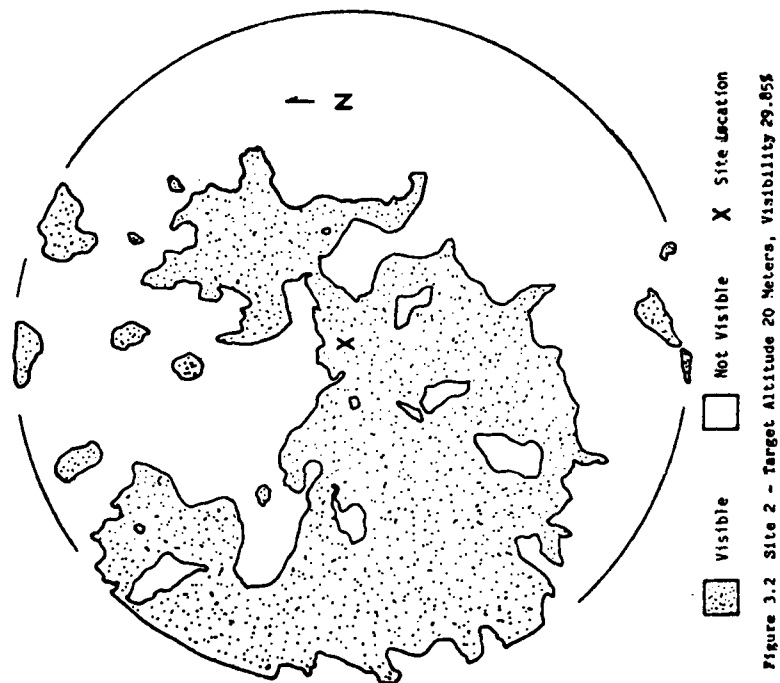
Lastly, in Figure 3.4, a poor site location is shown. Visibility at this site varies from 5.31 percent at 20 meters to 8.63 percent at 50 meters. Coverage provided by this site is southerly.

These three site locations are deployed in the same area and the composite coverage is shown in Figure 3.5. In the overall coverage, the poorly situated site provides sensor detection to the south which the other sites lack. Thus, the poor location is better than expected because it furnishes satisfactory coverage when considering the combined coverage.

As can be seen in these series of figures, the coverage of an area by air defense sensors limits the ability of an aircraft to penetrate the area undetected. The deployment of several air defense sites imposes a visibility constraint on the selection of routes through the area. It may be impossible to find an undetectable corridor.

3.4 Terrain Data

The terrain data base used in this research is Defense Mapping Agency (DMA) terrain data which provides the height above sea level for



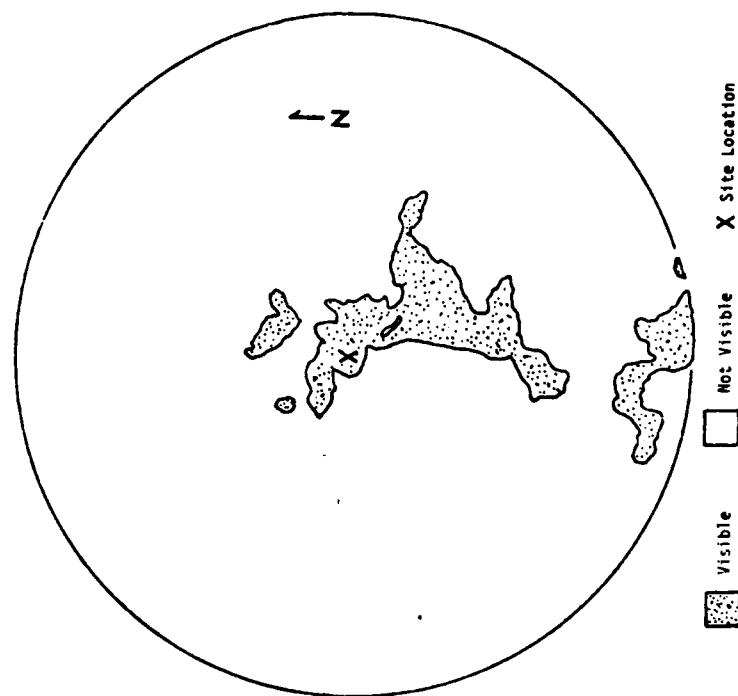


Figure 3.3 Site 2 - Target Altitude 50 Meters, Visibility 83.10%

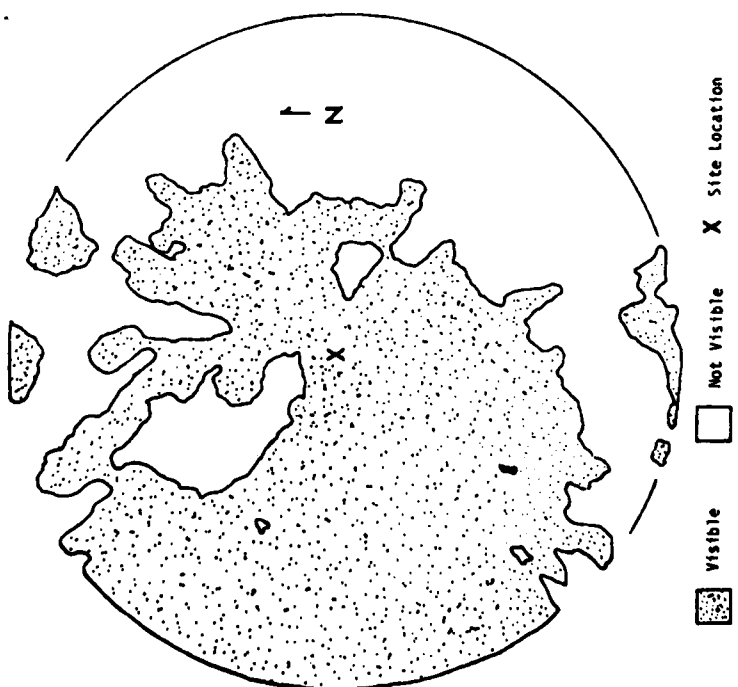


Figure 3.4 Site 3 - Target Altitude 20 Meters, Visibility 5.31%

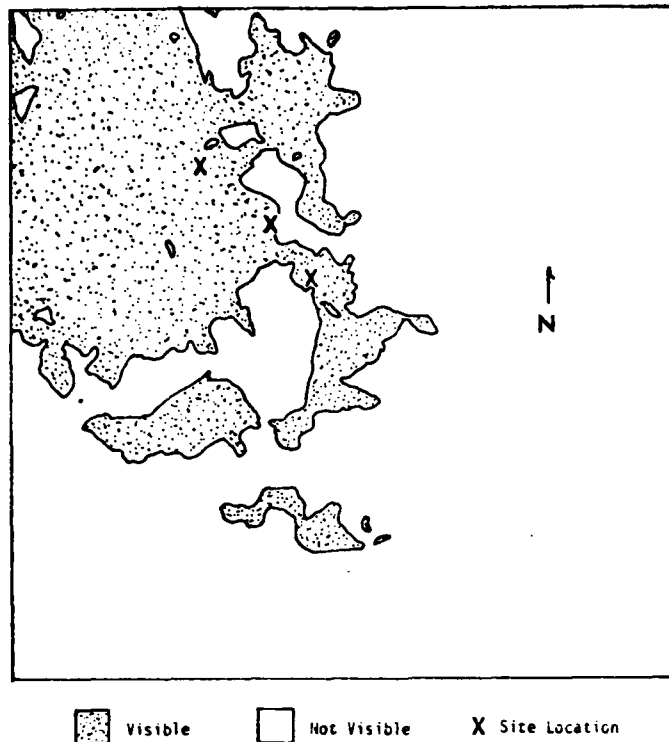


Figure 3.5 Composite of Sites 1, 2, and 3, Target Altitude 20 Meters

each terrain location. A granularity of 70.0 meters was selected in utilizing the data base. A problem with this fine a grid is the quantity of data points for even a moderate size area. For a 20 by 20 km area, this density results in 90,000 entries.

The first requirement in utilizing this data is to convert from a packed format into an array format of unpacked terrain points. The geographical area selected requires a 525 by 525 array (35 by 35 km). Since this array is too large for efficient computer processing, the area was partitioned into smaller arrays of 15 by 15. This arrangement results in a strip of 35 arrays to cover the north-south direction and 35 strips in the east-west direction (Figure 3.6). A map sheet is 15 data points from west to east, and 35 arrays of 15 data points from south to north.

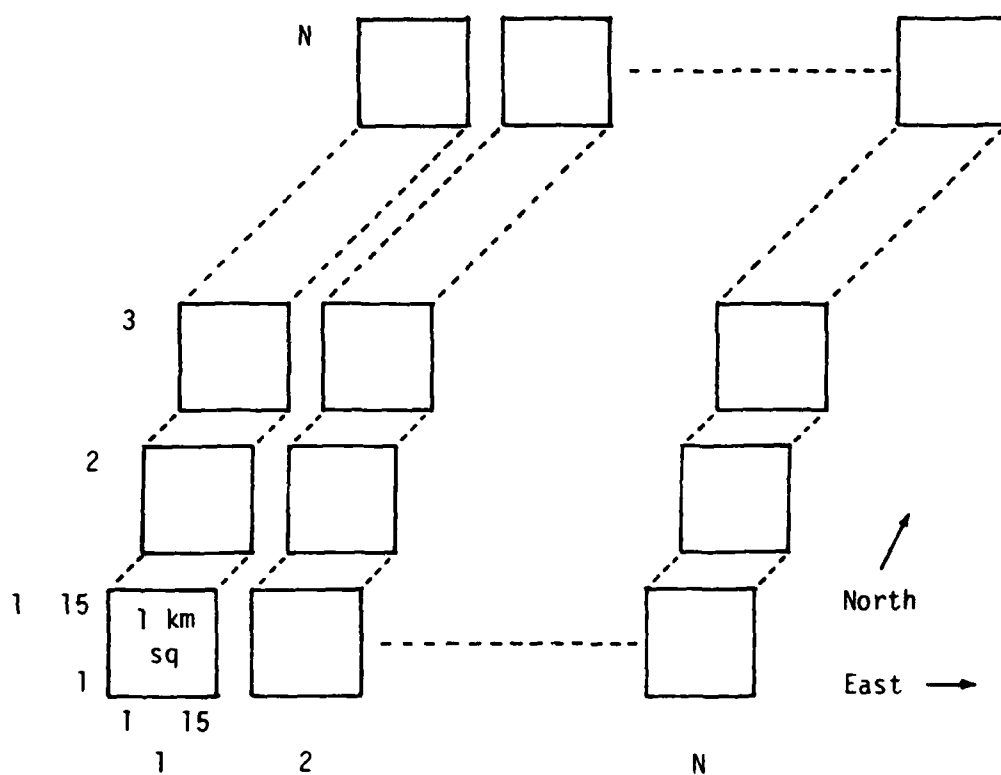


Figure 3.6. Terrain Data Arrays.

Once the terrain data is available from the conversion processing, some assumptions need to be made relating the data to the route selection problem. The premise that the aircraft route will follow the valleys and low areas requires that the low elevation terrain be identified from the terrain data. Thus, it is assumed that by a grouping or clustering process, these low elevation areas can be found. Also, the partitioning of the area allows for identification of local minimum altitudes rather than a single global value.

An example of terrain data arrays is shown in Table 3.1. As can be seen in this table, the variation in the point to point values can be stratified. Once the data is grouped into elevation intervals (or bands), the terrain relief is shown as plateaus with the lowest plateau being the lowest elevation area. The lowest stratum is a cluster of lowest terrain points from which the cluster center can then be used as a node point in the routing network.

With the terrain data analyzed and the node points established, the route can now be developed. The terrain route for the helicopter has only two known points at the onset - the initial point and the terminal point. All intermediate route points need to be selected from the nodes.

CHAPTER IV

MODEL DEVELOPMENT

4.1 Introduction

The route selection development begins with the basic terrain elevation data and ends with the minimum-exposure, and minimum elevation route. The model consists of several logical divisions that progressively solves this problem.

Initially, the model groups the terrain data into elevation bands from which cluster centroids (or centers) are developed. These centers become the node points for a routing network. Around a route node a neighborhood of node points is selected as possible links to this node. In this neighborhood each point has an exposure value which is a function of its visibility to enemy sensors, its altitude, and its distance from the node point. The exposure value is a penalty for the use of this point. Each linkage is a path or leg of the route, and all the linked nodes form a route connecting the minimum-exposure, and minimum-elevation points. The resulting path between the initial and final nodes provides a route for a penetrating low flying aircraft.

4.2 Clustering of Terrain Data

To group the terrain data into elevation bands the integer arithmetic feature of Fortran software is exploited. When arithmetic operations are performed on integer numbers, only the integer portion is

retained and the decimal portion is discarded. The following relation is utilized:

$$NE = (((E - 1)/INT) INT) + INT$$

where NE = the new elevation value,

E = the old elevation value,

INT = the band interval.

This calculation results in all elevation values within an INT interval of each other being assigned the maximum value of that interval. The process is identical to class intervals utilized in constructing a frequency table in statistical analysis. Instead of using the midpoint of the interval, the maximum in the class interval is used.

Once all the terrain data is stratified, then clusters of both high and low elevation points can be found. Each array of 15 by 15 covers an area of 1050 by 1050 meters. Within this area at least one low elevation cluster is identified along with a high elevation cluster. There are some cases where the whole array represents level terrain and the array consists of the same elevation values. When this situation occurs, it is necessary to check adjacent arrays to determine if this terrain is a low elevation cluster.

Since more than one low elevation cluster can occur in an array a method was developed to determine if two points were adjacent to each other. For a square grid a single point I has eight points around it as shown in Figure 4.1. The points labeled A through Q (less I) form a ring around the numbered points and cannot be adjacent to the point I.

5	---	A	B	C	D	E	---	
6	---	F	1	2	3	G	---	
7	---	H	4	I	5	J	---	
8	---	K	6	7	8	L	---	
9	---	M	N	O	P	Q	---	
		6	7	8	9	10		

Figure 4.1 Points Adjacent to I

The array is processed sequentially by searching across each row; therefore, cluster membership is identified in order of occurrence from the beginning of the array. For example, assume that a cluster consists of the following points - I, 5, J, 7, 8 and P. These six points are a cluster located in the 15 by 15 array. The clustering procedure identifies all points of the same elevation by entering their position into a list. The indexes of a point are combined by letting $INDEX = 100 (IROW) + JCOL$, where IROW is the row index and JCOL is the column index. This coded number is the location of the point within the array.

In this example, let the point I be in row 7, column 8. The stored INDEX value for I is 708. The other cluster membership values are given in Table 4.1.

Table 4.1 Cluster Membership

Member	INDEX Value	I-Difference
I	708	0
5	709	1
J	710	2
7	808	100
8	809	101
P	909	201

When searching this list for cluster membership the value of INDEX provides a means to separate clusters. Since the membership is sequential, only those points occurring after I need to be examined (points 5, 6, 7 and 8). By subtracting INDEX values the difference indicates adjacency.

For a point to be adjacent to I the difference must be either 1, 99, 100 or 101; any other value indicates that the point is separated by one or more rows (or columns). Points 5, 7, and 8 are identified as belonging to the same cluster as point I before considering the next point in the list. When point 5 is evaluated, point J is placed in the I cluster. The evaluation of point J does not add any new points to the cluster since all points adjacent to J are already in the cluster.

Point 7 evaluation adds the last point P to the cluster. This subtraction method is a quick process for identifying adjacency.

After determining which points are in the cluster, a center or centroid of the cluster can be calculated. Since the data points are planar, then each cluster has a centroid that is defined by the mean values for X and Y within the cluster:

$$(\bar{X}, \bar{Y}) = \left(\sum_{i=1}^n \frac{x_i}{n}, \sum_{i=1}^n \frac{y_i}{n} \right)$$

The centroids are now used as node points in the route selection process. The centroids are separated into two groups. If the centroid is for a low elevation cluster, it is placed in a low elevation array. Likewise, centroids for a high elevation cluster are placed in a high elevation array. The centroids in the high elevation array are identified by a minus sign. Figure 4.2 gives the location of the low and high elevation centroids that were found in the 10 by 10 km area utilized in the model development.

4.3 Sensor-Node Line of Sight

A major consideration in selecting a tactical aircraft route is to ensure that the route avoids enemy air defenses as much as possible. To determine the degree of visibility along a route, each centroid has to have its line of sight (LOS) to each sensor determined. The result of this determination is an exposure value associated with each node point.

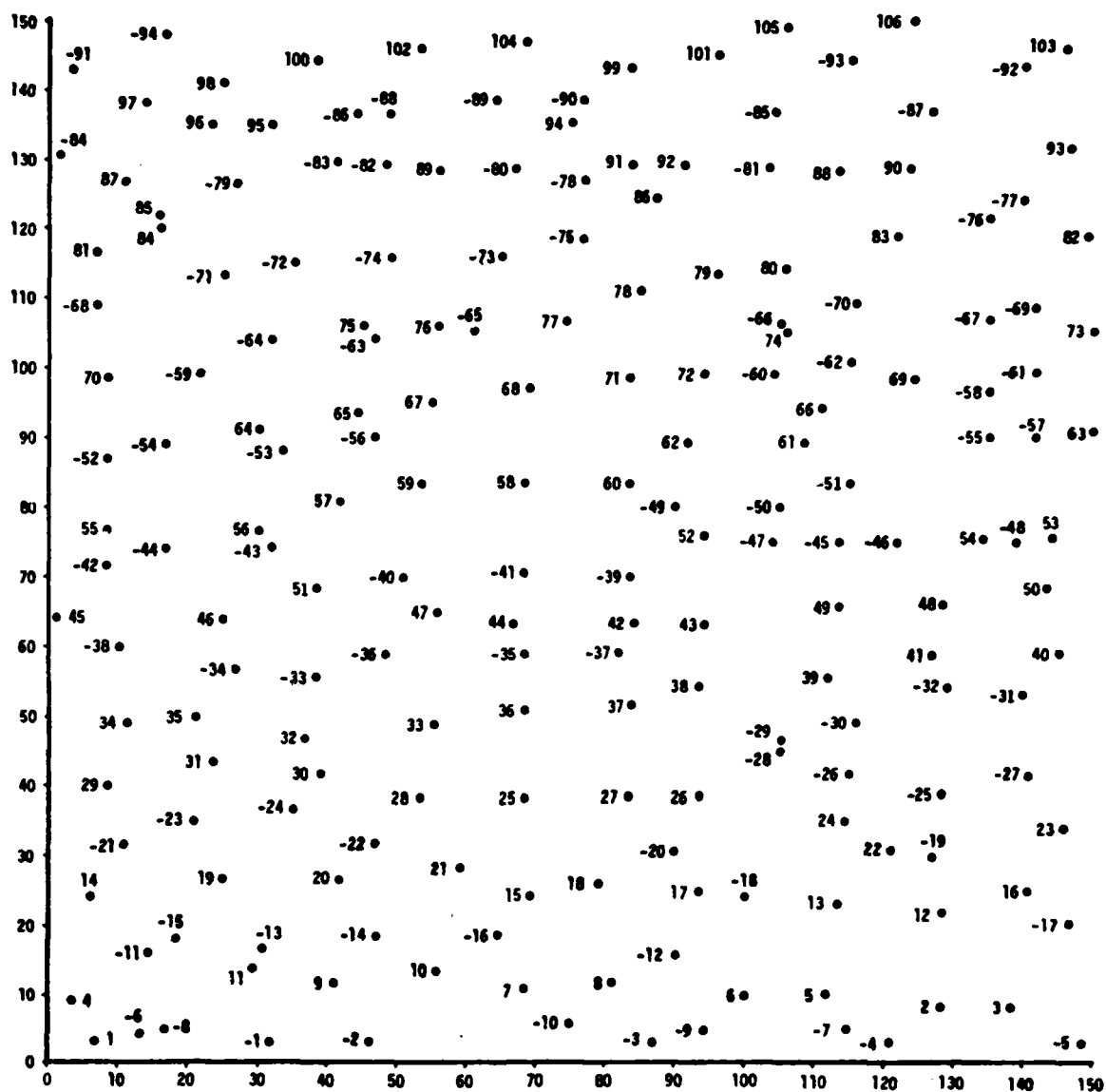


Figure 4.2 High and Low Nodes for Area One

To calculate the exposure value of a node point, the range between the node-sensor combination, together with the number of sensors, is required. The further a sensor is located from the node, the less of a threat it is since the probability of kill (P_k) is partially a function of range. However, the number of air defense sites having visibility to a point will increase the P_k . Since the sensors will tend to be deployed behind and along the general flow of the main battleline, an average range to sensors was selected as an exposure value. The exposure value is given by:

$$EP = NS \cdot \left[\frac{R_{\max} - \frac{\sum_{S=1}^{NS} R_{Sj}}{NS}}{R_{\max}} \right]$$

where EP = the exposure value for node j with all sensors that have LOS with this node,

NS = the number of sensors that have LOS with node j,

R_{\max} = the maximum node-sensor separation that exists for all node-sensor combinations,

R_{Sj} = the distance between the sensor and node j.

The value EP is calculated for all node-sensor combinations for both high and low elevation. As the route is being developed, the exposure values for the nodes are used as part of a penalty function. This discussion of the route selection is deferred to the next section.

For large areas of terrain, the data base has to be analyzed in segments or subareas that remain within computer core capacity. To satisfy

this restriction requires a bookkeeping method of array pointers to record the progress of the LOS calculations and which node-sensor pairs have been completed. ..

Referring back to Figure 3.6, the partition of the terrain data base is shown. Figure 4.3 presents the basic planar relationship between two nodes and a sensor. The + indicates the boundaries between each array of 15 by 15 terrain data points. Within this base the terrain elevation points represent X - Y coordinates of a square grid system. The vector between the node and sensor will intersect these grid lines and the array boundary lines. Along the X-axis the array boundary lines are also the map sheet boundary lines. Each intersection point of the vector and grid line is within 35 meters of a known elevation point. This known point is checked for masking of the node from the sensor. If masking occurs, the processing of this vector (or radial line as it is called in the air defense literature) is complete and the next node-sensor combination is processed [15]. If LOS exists at this intersection point, then the routine steps out of the vector to the next intersection. When the sensor location is reached and no masking terrain point has been encountered, then LOS exists between the node point and the sensor. The number of sensors which can see this node is then incremented by one.

To know which terrain point is along the LOS vector, the array indices are calculated from the vector-grid line intersection. The map sheets are read from west to east; therefore, all node-sensor vectors are oriented from west to east to allow one pass through all the data. In the model, the map sheet boundaries are named after the compass directions -

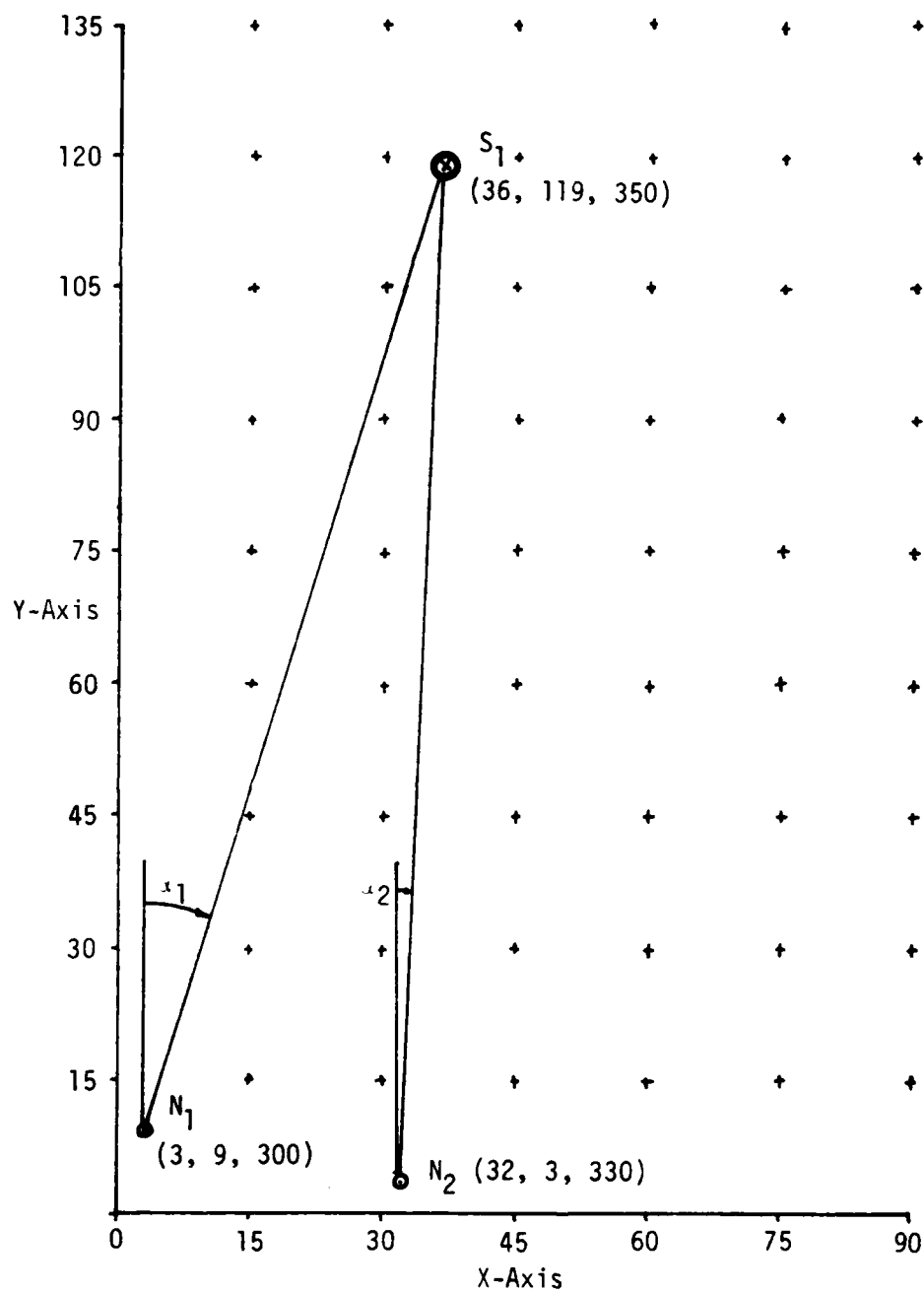


Figure 4.3 Sensor-Point Locations (X, Y, Z)

EAST, WEST, NORTH and SOUTH. As each map sheet is read, the previous EAST becomes the current WEST.

In Figure 4.3 the node point N_1 (3, 9, 300) and sensor location S_1 (36, 119, 350) define the end points of the vector $N_1 S_1$ with an azimuth angle α_1 . The other node-sensor vector is $N_2 S_1$ with an azimuth angle α_2 . The location of terrain points along these vectors becomes a trigonometric problem. The parameters defined below provide the indices needed to extract the terrain points from the data base.

$$d = \left[(x_2 - x_1)^2 + (y_2 - y_1)^2 \right]^{\frac{1}{2}}$$

$$\cos \alpha = (y_2 - y_1) / d$$

$$\sin \alpha = (x_2 - x_1) / d$$

$$\text{Comp } x = \begin{cases} 1 & , x_1 < \text{WEST} \\ (x_1 - \text{West}) + 1, & x_1 > \text{WEST} \end{cases}$$

$$\text{Left Comp } y = \begin{cases} \cos \alpha ((\text{WEST} - x_1) / \sin \alpha), & x_1 < \text{WEST} \\ 0 & , x_1 > \text{WEST} \end{cases}$$

where: d = the magnitude of the vector,

$\cos \alpha$ = the cosine of the azimuth angle,

$\sin \alpha$ = the sine of the azimuth angle,

Comp x = the x-axis component of the vector within the map sheet,

Left Comp y = the y-axis component of the vector for the West boundary.

From these parameters the row and column indexes can now be determined.

For a vector, the indices are given below.

$$\text{COLUMN (x-axis)} = \begin{cases} x + \Delta x & , |\sin \alpha| > \sin 45^\circ \\ (\Delta y / \cos \alpha) \sin \alpha + x & , |\sin \alpha| < \sin 45^\circ, x > \text{WEST} \\ (\Delta y / \cos \alpha) \sin \alpha + x - \text{WEST} + 1, & |\sin \alpha| < \sin 45^\circ, x < \text{WEST} \end{cases}$$

$$\text{ROW (y-axis)} = \begin{cases} y + \Delta y & , |\sin \alpha| < \sin 45^\circ \\ (\Delta x / \sin \alpha) \cos \alpha + y & , |\sin \alpha| > \sin 45^\circ \end{cases}$$

The final value of the row index has to be transformed to indicate which array on the map sheet is the correct one. Thus, the final row index is given by integer arithmetic.

$$\text{ARRAY} = (\text{ROW} - 1) / 15$$

$$\text{ROW} = \text{ROW} - (\text{ARRAY} - 1)(15)$$

The terrain data located at (ROW, COLUMN, ARRAY) is checked to determine if its elevation will block the LOS. If it does not mask the node, the indices are incremented to the next value to be evaluated. After all node-sensor combinations have been processed, the route development can begin.

4.4 Route Selection.

With the node points for a route and their visibility determined, the method for linking these nodes into a route can be finalized. Two other characteristics of a node need to be considered along with its visibility. The first is its elevation in relation to surrounding nodes and the second is the distance to these surrounding nodes.

To determine the area size that should be considered a neighborhood about a node, several military helicopter pilots were contacted to discuss terrain following or nap of the earth flying. These pilots unanimously report that a range of one kilometer is utilized to consider their next position. Even though major terrain features used for reference points can be seen several kilometers away, terrain following flights require a pilot to concentrate on the immediate area to avoid terrain impact. Therefore, one kilometer was selected as the rectilinear distance about a node to define a neighborhood.

Depicting the relationship of nodes in a neighborhood, Figure 4.4 contains the nodes surrounding nodes 13 and 17. These nodes are in the neighborhood of either 13 or 17. Table 4.2 lists these nodes, the coordinates, and the distance from the center (1 unit = 70 meters). The negative nodes are the high elevation centers and the positive nodes are the low elevation centers. As can be seen in Figure 4.4 and Table 4.1, five nodes are shared by nodes 13 and 17.

With this information, a value can be assigned to these neighborhood nodes based on their elevation and distance from the primary node. The higher elevation nodes would normally be avoided in favor of traveling to a low elevation node. A penalty for height is added to the exposure value of each node by the following factor.

$$ZP_j = \left(\frac{Z_j - Z_{min}}{ZR} \right)$$

where ZP_j = the penalty assigned to node j ,

Z_j = the elevation of node j ,

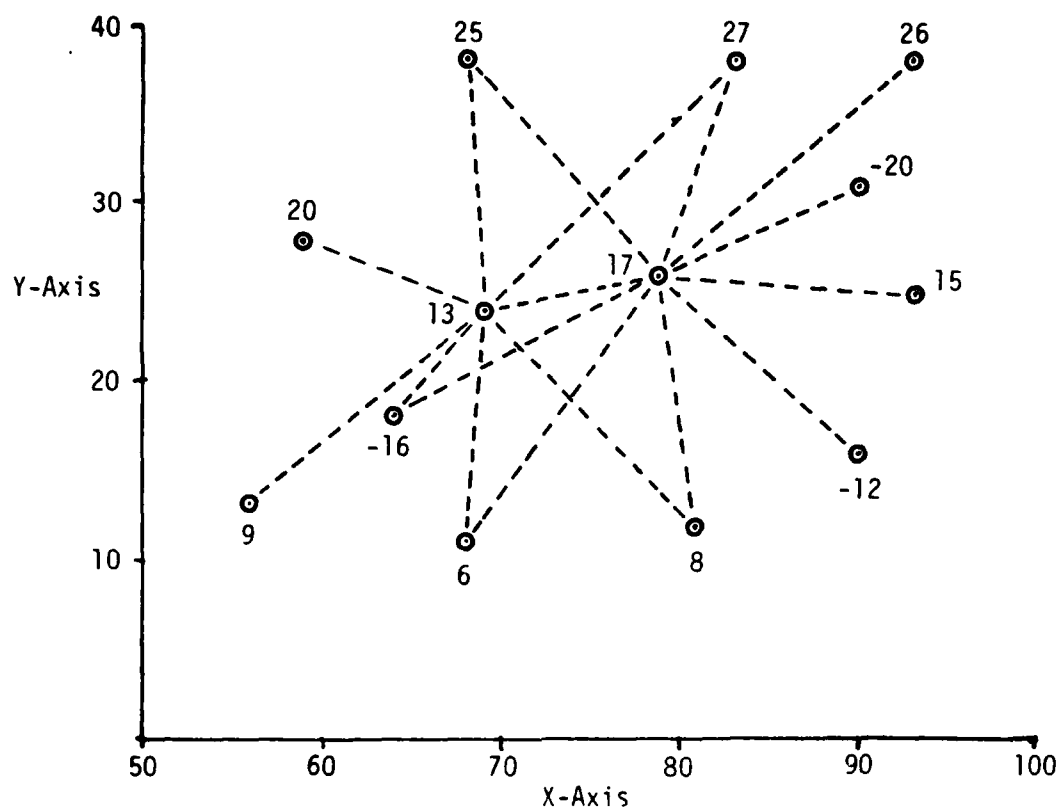


Figure 4.4 Node Linkage

Table 4.2 Node Links

Node 13 (113, 23, 300)				
No.	(X,Y,Z)	Distance	No.	(X,Y,Z)
6	(100, 10, 300)	13.038	20	(42, 27, 290)
8	(8, 10, 300)	16.971	25	(68, 8, 280)
9	(41, 12, 300)	17.029	27	(83, 38, 280)
17	(93, 25, 290)	10.198	-16	(64, 18, 290)
Node 17 (93, 26, 290)				
No.	(X,Y,Z)	Distance	No.	(X,Y,Z)
6	(100, 10, 300)	18.601	26	(93, 38, 280)
8	(81, 21, 290)	14.142	27	(83, 38, 280)
13	(113, 23, 300)	10.198	-12	(70, 16, 300)
15	(69, 24, 280)	14.036	-16	(64, 18, 290)
25	(68, 38, 280)	16.279	-20	(90, 31, 290)

Z_{\min} = the minimum elevation of the neighborhood nodes,

ZR = the range between the maximum and minimum elevation in the neighborhood.

$$0 \leq ZP_j \leq 1$$

To account for distance from the central node, the penalty is associated with traveling short distances rather than long distances. The idea is to travel as far as possible in the neighborhood to reach a low, least exposed node. Thus the distance factor is given by:

$$DP_j = \left(1 - \frac{D_j - D_{\min}}{DR} \right)$$

where DP_j = the penalty for a short distance between the central and neighborhood node,

D_j = the distance to the neighborhood node j ,

D_{\min} = the minimum distance,

DR = the range between the maximum and minimum distance in the neighborhood.

$$0 \leq DP_j \leq 1$$

Adding these two factors to the exposure value results in the following function.

$$EP_{\min j}(ij) = NS \cdot \left[\frac{R_{\max} - \sum_{S=1}^{NS} R_{Sj}}{NS} \right] + \left(\frac{Z_j - Z_{\min}}{ZR} \right) + \left(1 - \frac{D_j - D_{\min}}{DR} \right).$$

The linkage (ij) is from node i to node j for which j is the minimum value within the neighborhood. Since each point and neighborhood is considered independently of any previous neighborhoods, this method is a dynamic programming approach to solving this problem.

The route objective is to provide a path to the terminal position. Therefore, some weighting should be given to those nodes which lie in the general direction of travel. To implement this idea, the vector-heading from the current position to the terminal node is found. The nodes which lie within 90° of either side of this heading have a weight of 1. Those nodes greater than 90° are located behind the current position and have a weight of 2. The exposure penalty of a neighborhood node is multiplied by this weight to give preference to those nodes which are ahead of the current position. If a position behind the current one has a very low exposure penalty it can still be selected, but the route procedure will reorient to the terminal node and will favor the destination direction.

When the route model has reached a position within 1 km of the terminal node the weighting scheme is modified to be more selective. The angle of preference is reduced to 45° of the route heading and pertains to those nodes lying inside the 1 km range. The weighting schemes for the selection process are given in Figures 4.5 and 4.6.

In developing the model, it was found that these weighting schemes lack one vital criterion - radar avoidance. The first two weightings provide the model with decision logic which improves the performance considerably; however, if the minimum exposure point was located on the other side of a sensor, then the logic would still choose this same point even though the route would then be directly over the sensor. After some testing of the model, a radar avoidance scheme was added to the weighting preference.

Air defense radars usually will have an acquisition range greater than the engagement range of the weapon system (guns or missiles). An

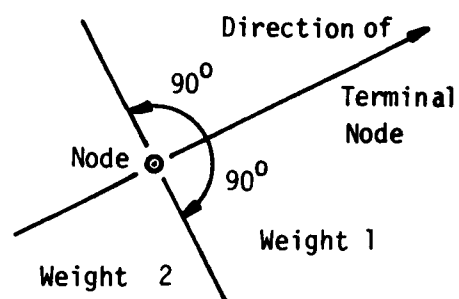


Figure 4.5 Weighting of Heading

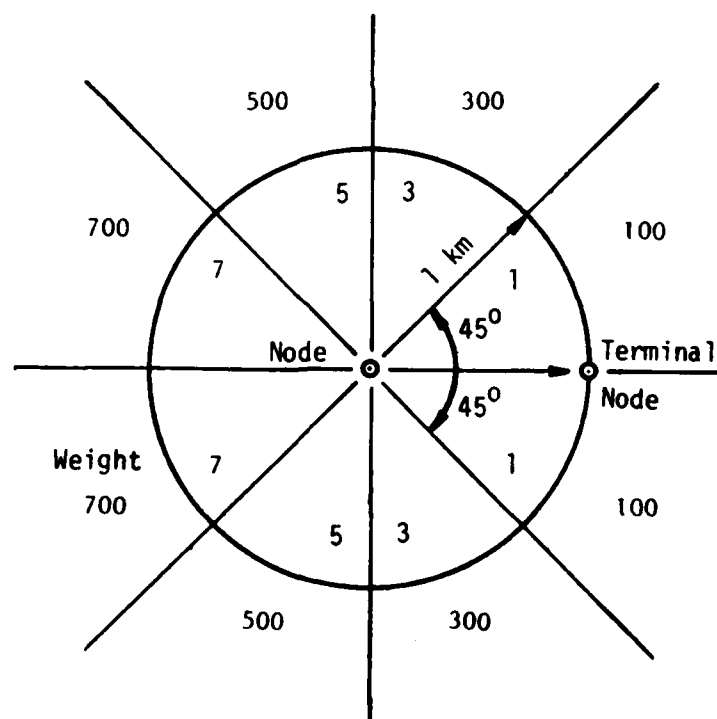


Figure 4.6 Weighting of Terminal Node

engagement boundary around the air defense site is assumed to be the weapon's kill radius. A vector from the current position to the sensor is calculated to give the azimuth and range to the sensor. A cone is used to form a high rejection area for nodes. The current position is the apex of the cone and the base is twice the kill radius, with the sensor at the base midpoint. A neighborhood node lying in this cone and ahead of the kill zone has a weight of 2. If it lies beyond this boundary the weight is 10. A node point which would cause the route to overfly or pass too close to the air defense site is thus avoided.

Figure 4.7 shows the relationship between the current node and the sensors, the terminal node and the new node. The angles shown in the figure are utilized in calculating the weighting values. Integer arithmetic allows a uniform weight to be assigned within any one area. The equations for calculating these weightings follows.

Angle of new node j from destination heading is:

$$ANT = \begin{cases} AN_j - AH & , -180^\circ \leq ANT \leq 180^\circ \\ AN_j - AH + 360^\circ, & ANT < -180^\circ \\ 360^\circ + AH - AN_j, & ANT > 180^\circ \end{cases}$$

Direction Weight is:

$$W_j = |ANT|/90^\circ + 1$$

Terminal Weight is:

$$RW_j = \begin{cases} 2|ANT|/45^\circ + 1 & , < 1 \text{ km} \\ (2|ANT|/45^\circ + 1) 100 & , > 1 \text{ km} \end{cases}$$

Radar Avoidance Weight is:

$$AW_j = \begin{cases} 0, & AS - AN_j > AK \\ 2, & RN_j > RS - RK, AS - AN_j < AK \\ 10, & RN_j < RS - RK, AS - AN_j < AK \end{cases}$$

Where the variables in the equations and Figure 4.7 are:

- AN_j = the angle from the x-axis to the new node j,
- AH = the angle from the x-axis to the terminal node,
- ANT = the angle between the new node and the terminal node,
- AS = the angle to the sensor from the x-axis,
- AK = the angle to each side of the sensor heading which would be within the kill radius,
- RS = the range to the sensor from the current route node,
- RK = the kill radius of the weapon system,
- RN_j = the distance to the new node j,

The final exposure penalty for a node is defined by:

$$N_k = \min_j (W_j + RW_j + AW_j) \cdot EP(ij)$$

Where N_k = the next node selected for the route,

W_j = the weight of node j based on its angle heading,

RW_j = the weight of node j based on its range to terminal node,

AW_j = the weight of node j based on whether or not it lies in the radar avoidance cone.

4.5 Route Refinement

A review of the resulting routes as developed by the model indicates a need for route refinement; therefore, it is necessary for the route selection logic to evaluate whether or not route nodes are

adjacent to each other. In an attempt to avoid air defense sites, the route may double back on itself. Thus, the route must be refined by determining if each node j ahead of the current position i is the closest one. If, for example, the ninth route node ahead of the current one is the closest position, then that node becomes the next node to link with node i . Node i is linked to node j by the following relation.

$$L(ij) = \min_j [(x_j - x_i)^2 + (y_j - y_i)^2]^{\frac{1}{2}}$$

$$j = i + 1, \dots, n$$

where $L(ij)$ = the link between i and j ,
 (x_i, y_i) = the current node position,
 (x_j, y_j) = the next node position.

With this refinement to the model route logic, a shorter more direct route to the destination can be found. With the model development complete, an example will be given in the next chapter.

CHAPTER V

ROUTE SELECTION EXAMPLE

5.1 Introduction

The model is now utilized in selecting a route. The example described in this chapter is a portion of a route found by the model. Additional route problems that were solved by the model are contained in Appendix A. The general computer outline of the model and each subroutine is given in Appendix B. In addition the model software is commented throughout for ease in understanding the logic.

The area of analysis is 10 by 10 km. This size area is large enough to exercise the model yet small enough to run in 30 CPU seconds (6.5 seconds compile, 23.04 execution). The actual terrain is rolling hills with an elevation range from 270 to 400 meters. Within this area, 3 sensors are located to provide radar coverage.

Two positions were arbitrarily selected on opposite sides of the area as an initial and terminal node. These two positions are situated such that the three sensors are between these points. Any route found will have to consider node positions that lie near the sensors since they act as a barrier to be crossed.

5.2 Elevation Nodes

The initial part of the model provides the clustering of terrain data into high and low elevation groups. Within each group a center is found that becomes a node point for selection. The example clustering results were 106 low elevation nodes and 94 high elevation nodes.

Within the low elevation group, the initial and terminal nodes are inserted so that when the nodes are ordered by rows they will be in sequence. The first node is also the initial node. The terminal node is number 86. All high nodes are indicated by a minus sign.

5.3 Line of Sight Calculations

The amount of calculation required in identifying the nodes is minimal and consists mostly of comparisons and list searching. The first portion requiring any degree of computation is the LOS calculation in subroutine RADIAL.

For these calculations low elevation node 10 and high elevation node -11 were selected as examples for determining LOS. Two sensors will be used, as the calculations for more combinations are the same. The coordinates of the two nodes and sensors are given in Table 5.1.

Table 5.1 Node-Sensor Coordinates

Node (N_i) (X, Y, Z)	Sensor (R) (X, Y, Z)
10 (29, 14, 310)	1 (68, 70, 300)
-11 (12, 16, 330)	2 (47, 99, 310)

The first step performed by the model is to determine if the node or sensor is the western most point. Comparing X values in Table 5.1 indicates that both nodes are to the West of sensor 1. Node 10 will be analyzed first.

Table 5.2 gives the initial values for the variables used in this example. The horizontal scale is one unit equals 70 meters and the vertical values are in meters.

Table 5.2 Parameter Values

Map Sheet	2
EAST	30
WEST	16
SOUTH	1
NORTH	150
Earth Curvature (RE) (radar 4/3)	8490200.0 meters
Vehicle Height (V) (Aircraft)	10.0 meters
Sensor Height (S)	3.0 meters
GRID	70.0 meters

The first value needed is the horizontal distance between the node and the sensor.

$$d = [(x_2 - x_1)^2 + (y_2 - y_1)^2]^{\frac{1}{2}}$$

$$d = [(68 - 29)^2 + (70 - 14)^2]^{\frac{1}{2}}$$

$$d = 68.242$$

The azimuth angle cosine and sine are:

$$\cos \alpha = (y_2 - y_1) / d$$

$$\cos \alpha = (70 - 14) / 68.242$$

$$= 0.821$$

$$\sin \alpha = (x_2 - x_1) / d$$

$$\sin \alpha = (68 - 29) / 68.242$$

$$= 0.571$$

The tangent between these two points will determine whether the eastern point lies above or below the horizontal as measured from the western point. When calculating the tangent, the height of the vehicle and sensor are added to the appropriate point. In addition, the earth curvature for the radar beam atmospheric refraction is accounted for by the following relation [16].

$$\begin{aligned}
 \text{Ref} &= 0.5 (d)(d)/(RE/GRID) \\
 \text{Ref} &= 0.5 (68.242)(68.242)/(8490200.0/70) \\
 &= 2328.5/121288.57 \\
 &= 0.0192
 \end{aligned}$$

The tangent is:

$$\begin{aligned}
 \text{Tan } \beta &= ((Z_R + S) - (Z_{N_i} + V) - \text{REF})/(d)(GRID) \\
 \text{Tan } \beta &= (303 - 320 - 0.0192)/(68.242)(70) \\
 &= -0.0036
 \end{aligned}$$

The absolute value of $\sin \alpha$ is compared to the sine of 45° . Since $0.571 < \sin 45^\circ$, then the direction is either north or south. The cosine is a positive 0.821 which indicates a north heading. When the cosine is negative, a south heading is indicated. The y position is found for the north or south direction by incrementing y by one plus any west boundary offset. In this example the Left Comp y is zero. The integer value of y is used for the data base row index and is found by integer arithmetic.

$$\begin{aligned}
 \text{ROW} &= y + \Delta y \\
 &= 14 + 1 = 15 \\
 \text{ARRAY} &= (\text{ROW} - 1)/15 + 1 \\
 &= (15 - 1)/15 + 1 = 1.93 = 1 \\
 \text{ROW} &= \text{ROW} - (\text{ARRAY} - 1)(15) \\
 &= 15 - (1 - 1)(15) = 15
 \end{aligned}$$

The column position can be found by the following.

$$\begin{aligned}
 \text{COL} &= (\Delta y / \cos \alpha) \sin \alpha + x - \text{WEST} + 1 \\
 &= (1/0.821) (0.571) + 29.0 - 16 + 1 \\
 &= 14.70 = 14
 \end{aligned}$$

The position of the first point to be extracted from the data base is located at (ROW, COL, ARRAY) = (15, 14, 1) of the second map sheet.

Now that the elevation of 308 has been found at this point a tangent is calculated to determine if this new point masks node 10 from sensor 1.

The distance to the new point, d' , is given by:

$$\begin{aligned} d' &= \Delta y / \cos \\ &= 1 / 0.821 = 1.22 \\ \text{Ref}' &= 0.5 (1.22)(1.22) / (8490200.0 / 70) \\ &= 0.5 (1.22)(1.22) / 121288.57 \\ &= 0.000006 \end{aligned}$$

Tangent α for the new point is calculated by:

$$\begin{aligned} \tan \alpha &= (Z_n - (Z_i + V) - \text{Ref}') / (d')(70) \\ \text{where } Z_n &= \text{the elevation of the new point.} \\ \tan \alpha &= (308 - 320 - 0.000006) / (1.22)(70) \\ &= -0.14 \end{aligned}$$

Since $\tan \alpha < \tan \beta$, this new point does not mask the node (-0.14 < -0.0036). The value of y is incremented to find the next grid point to be extracted from the data base.

$$\begin{aligned} y &= 2 \\ \text{ROW} &= 14 + 2 = 16 \\ \text{ARRAY} &= (16 - 1) / 15 + 1 = 2 \\ \text{ROW} &= 16 - (2 - 1)(15) = 1 \\ \text{COL} &= (2 / 0.821) (0.571) + 29.0 - 16 + 1 \\ &= 15.39 = 15 \end{aligned}$$

The second point from the data base is located in position (1, 15, 2) (Z = 304). Since the column is equal to 15, the eastern edge of the map sheet has been reached. In this case this second point does not mask the node, but any further calculations have to wait until the third map sheet is read into core storage.

The second node, number -11, is located on map sheet 1. Since this example began on map sheet 2, then the procedure for starting on the second map sheet, where the first map sheet processing stopped, will be shown. The basic calculations of sine, cosine, etc. are similar and are given below:

$$d = [(68 - 12)^2 + (70 - 16)^2]^{\frac{1}{2}}$$

$$= 77.795$$

$$\cos \alpha = (70 - 16)/77.795$$

$$= 0.694$$

$$\sin \alpha = (68 - 12)/77.795$$

$$= 0.720$$

$$\text{Ref} = 0.5 (77.795)(77.795)/(121288.57)$$

$$= 0.0249$$

$$\tan \alpha = (303 - 340 - 0.0249)/(77.795) (70)$$

$$= -0.0068$$

In this case, $\sin \alpha > \sin 45^\circ$; thus the direction is east. For a easterly vector the value of x is incremented by one to find the next position, but the value of y is calculated. Since $x < \text{WEST}$, x and COL are set to 1. The row index of y is calculated by

$$\text{ROW} = (\Delta x / \sin \alpha) \cos \alpha + y$$

$$= ((16 - 12 + 1) / 0.720) 0.694 + 16$$

$$= 20.82$$

$$\begin{aligned}
 \text{ARRAY} &= (\text{ROW} - 1)/15 + 1 \\
 &= (20.82 - 1)/15 + 1 = 2 \\
 \text{ROW} &= \text{ROW} - (\text{ARRAY} - 1)(15) \\
 &= 20.82 - (1)(15) = 5
 \end{aligned}$$

The first position in the second map sheet for node -11 is (5, 1, 2). The tangent of this new point is calculated the same as shown for node 10. The $\tan \alpha < \tan \beta$ in this case; therefore, the next position on the vector is found and checked for LOS.

The result of these computations is the number of sensors which can see this node. Having obtained this count on each node-sensor combination the exposure value for the node can be computed. For node 10 the count is 3, since all sensors can see this node. The R_{\max} value for the node-sensor combinations in this example was found to be 161.941. The sum of the distances to the three sensors is 252.589. The exposure value is:

$$\begin{aligned}
 \text{EP} &= \text{NS} \cdot \left[\frac{R_{\max} - \frac{\sum_{S=1}^{\text{NS}} R_{Sj}}{\text{NS}}}{R_{\max}} \right] \\
 &= 3 \cdot \left[\frac{161.941 - \frac{252.589}{3}}{161.941} \right] \\
 &= 1.440
 \end{aligned}$$

5.4 Route Selection

For the route selection method, the initial point and the next to last point along a route were chosen as examples. The initial point is

also node 1 (7, 3, 270) and the terminal point is node 86 (87, 124, 310). Starting at node 1, the route seeks the minimum exposure point in the neighborhood. The nodes surrounding node 1 are given in Table 5.3.

Table 5.3 Neighborhood Nodes

Node	(x, y, z)	Distance	Exposure Value
4	(3, 9, 300)	7.211	0.672
-6	(13, 4, 400)	6.083	1.122
-8	(17, 5, 400)	10.198	1.167
-11	(12, 16, 330)	13.928	1.310

The distance and height penalties are now added to the exposure value for these points. The height penalty is given as:

$$ZP_j = \frac{Z_j - Z_{\min}}{ZR}$$

$$ZP_4 = \frac{300 - 300}{100} = 0.0$$

$$ZP_{-6} = \frac{400 - 300}{100} = 1.0$$

$$ZP_{-8} = \frac{400 - 300}{100} = 1.0$$

$$ZP_{-11} = \frac{330 - 300}{100} = 0.3$$

The distance penalty is:

$$DP_j = 1.0 - \left(\frac{D_j - D_{\min}}{DR} \right)$$

$$DP_4 = 1.0 - \left(\frac{7.211 - 6.083}{7.845} \right)$$

$$= 1.0 - 0.144 = 0.856$$

$$\begin{aligned}
 DP_{-6} &= 1.0 - \left(\frac{6.083 - 6.083}{7.845} \right) \\
 &= 1.0 \\
 DP_{-8} &= 1.0 - \left(\frac{10.198 - 6.083}{7.845} \right) \\
 &= 1.0 - 0.525 = 0.475 \\
 DP_{-11} &= 1.0 - \left(\frac{13.928 - 6.083}{7.845} \right) \\
 &= 1.0 - 1.0 = 0.0
 \end{aligned}$$

The final penalties associated with these nodes are:

Node 4 1.528
 Node -6 3.122
 Node -8 2.642
 Node -11 1.610

The direction weighting of these penalty values are determined by computing the azimuth of the terminal and neighborhood nodes. Table 5.4 gives the azimuth angle to the nodes, their weight and their final penalty value.

Table 5.4 Weighted Penalty Value

From	To	Angle x-axis	Angle from Heading	Weight	Penalty
1	86	56°	0°	-	-
1	4	123°	67°	1	1.528
1	-6	9°	-47°	1	3.122
1	-8	11°	-45°	1	2.642
1	-11	68°	12°	2	3.220

To compute the Table 5.4 entries for node 4 the following values are found using integer arithmetic.

$$\begin{aligned}\text{x-axis } AN_4 &= \text{ARCTAN } (Y/X) \\ &= \text{ARCTAN } ((9-3)/(3-7)) \\ &= -56.31^\circ\end{aligned}$$

Since the angle is negative, it is subtracted from 180° .

$$AN_4 = 180^\circ - 56.31^\circ = 123.69^\circ = 123^\circ$$

$$ANT = 123^\circ - 56^\circ = 67^\circ$$

$$\begin{aligned}\text{Weight } W_j &= ANT / 90^\circ + 1 \\ &= 67^\circ / 90^\circ + 1 \\ &= 0 + 1 = 1\end{aligned}$$

$$\begin{aligned}\text{Penalty } EP_{ij} &= (W_j) (EP_j) \\ &= (1)(1.528) = 1.528\end{aligned}$$

Node -11 is the only one in Table 5.4 that utilized the radar avoidance weighting. Sensor 2 is almost collinear with nodes 1 and -11. For this example, the weapon system kill radius is 1.5 km or 21.43 in units of 70 meters. The calculations below would be made for all sensors and all nodes in the neighborhood, however, only node -11 is affected in this case.

Angle to sensor 2 is given by:

$$\begin{aligned}\text{x-axis } AN_{-11} &= \text{ARCTAN } (Y/X) \\ &= \text{ARCTAN } ((99 - 3)/(47 - 7)) \\ &= 67.38^\circ = 67^\circ\end{aligned}$$

Angle of 1/2 cone is given by:

$$\begin{aligned} RS &= [(99 - 3)^2 + (47 - 7)^2]^{\frac{1}{2}} \\ &= 104.00 \\ AK &= \text{ARCTAN } (21.43/104.00) \\ &= 11.64^\circ \end{aligned}$$

Angle between sensor 2 and node -11 is given by:

$$\begin{aligned} &AS - AP \text{ (from Table 5.4)} \\ -1^\circ &= 67^\circ - 68^\circ \\ -1^\circ &< 11.64^\circ \end{aligned}$$

Therefore, node -11 is in the cone of high rejection.

$$\begin{aligned} AW_j &= 2, \text{ distance node -11} < \text{sensor 2} \\ &(13.9 < 104.00) \end{aligned}$$

The next to last node along the route, number 78, utilizes the terminal weighting scheme. The values associated with node 78 are in Table 5.5. In this table the terminal node 86 has the smallest weighted exposure. The values in Table 5.5 are computed as shown previously except for the weight entry. The weight value for nodes 71 and 72 are found below.

For node 71:

$$\begin{aligned} RW_j &= 2 \text{ ANT}/45^\circ + 1, \quad (13.153)(70) < 1 \text{ km} \\ &= 2 (-179/45) + 1 \\ &= 2 (4) + 1 = 7 \end{aligned}$$

Table 5.5 Node 78

From	To	Distance	Exposure	Height	Penalty	Distance	Penalty	Angle X-axis	Heading	Weight	Penalty
78	71	13.153	2.438	0.0		0.423		-98°	-179°	7	2009
78	72	15.000	2.306	0.0		0.000		-53°	-134°	500	115500
78	79	11.180	2.234	0.0		0.874		10°	-71°	3	933
78	86	13.153	0.730	0.5		0.423		81°	0°	1	163
78	-75	10.630	1.576	1.0		1.000		138°	57°	3	1059

For node 72:

$$\begin{aligned}
 RW_j &= (2 \text{ ANT}/45^\circ + 1) 100 \quad , \quad (15.0)(70) > 1 \text{ km} \\
 &= (2 (-134/45) + 1) 100 \\
 &= (2 (2) + 1) 100 = 500
 \end{aligned}$$

5.5 Route Refinement

To provide an example of route refinement consider the following situation given in Table 5.6.

Table 5.6 Linkage

From Node (X, Y, Z)		To Node (X, Y, Z)		Distance
31	(11, 45, 280)	30	(23, 43, 280)	12.166
30	—	28	(8, 40, 280)	15.297
28	—	35	(21, 50, 280)	16.401
35	—	34	(11, 49, 280)	10.050
34	—	45	(1, 64, 300)	18.028

The linkage between these points can be seen in Figure 5.1. From the figure, it is seen that node 34 is the closest node to node 31. The model determines this fact by comparing distances between nodes. The distance from node 31 to each of the nodes ahead of it is computed to the end of the route by the model; however, for this example, the process will stop at node 45. Table 5.7 gives the distance values for each of these nodes.

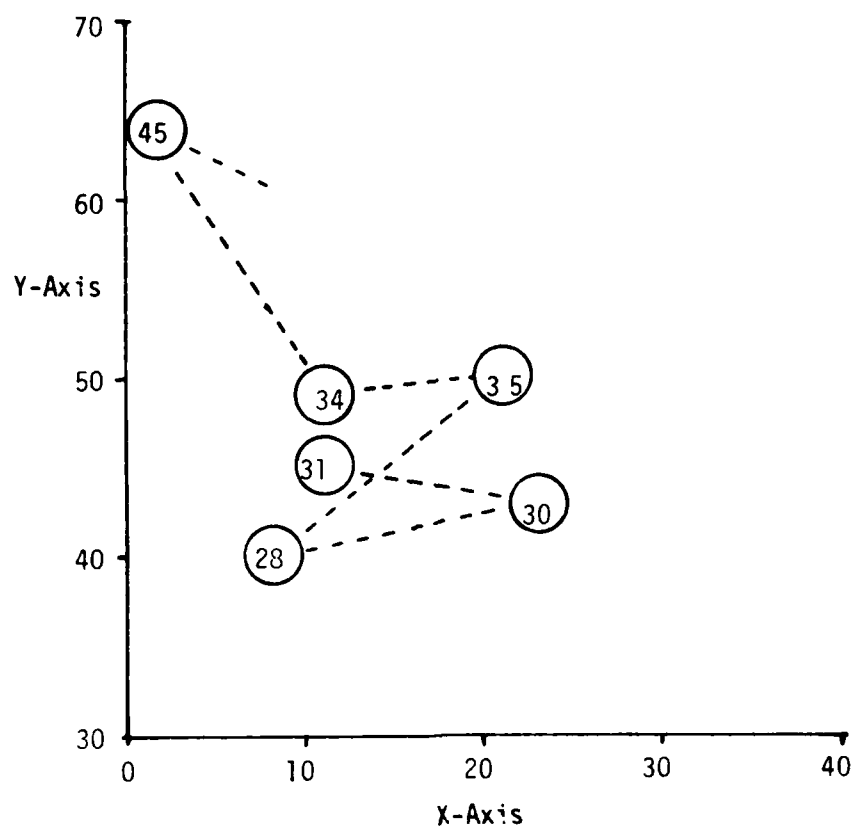


Figure 5.1. Linkage Example.

Table 5.7 Distance from Node 31

Node	Distance
30	12.166
28	5.831
35	11.180
34	4.000
45	21.471

The closest node to node 31 is node 34. In the refinement procedure, node 31 would be linked to node 34. Nodes 30, 28 and 35 would be eliminated from the route. The next node in the sequence, node 34, would now be compared with all nodes ahead of it for the closest node. The model continues to evaluate each new node on the route until the destination is reached. The results of this procedure become the refined route.

CHAPTER VI

MODEL RESULTS

6.1 Introduction

To evaluate the effect of sensor location on the route selection, two sets of sensor deployments were chosen along with two sets of beginning and end points. Since the test area was predominantly level terrain, a second small area was chosen of moderately rough terrain.

The results of the two small 10 by 10 km terrain areas are presented first, followed by the large 35 by 35 km area. To run the large terrain required increasing the dimensions of several primary arrays. The computer processing time for the large area increased by a factor of 10.

A plot of the route has proven to be the best analysis tool in evaluating the resulting routes. The tables provide the quantitative results; however, the route figures provide a visual comparison between routes that is discernible.

6.2 Small Area Analysis

The performance of this model was judged by varying sensor and route end points to provide different routes. Tables 6.1 and 6.2 provide the location of sensors and route end points utilized in the two small terrain areas. Each set of sensors was deployed against each route, resulting in four cases for each area as shown in Table 6.3.

Table 6.1 Sensor Locations

Area 1			
Set 1		Set 2	
Sensor	(X,Y,Z)	Sensor	(X,Y,Z)
1	(68, 70, 300)	1	(115, 116, 330)
2	(36, 119, 350)	2	(90, 84, 340)
3	(47, 99, 310)	3	(103, 45, 320)

Area 2			
Set 1		Set 2	
Sensor	(X,Y,Z)	Sensor	(X,Y,Z)
1	(28, 114, 330)	1	(78, 57, 350)
2	(61, 90, 380)	2	(85, 42, 340)
3	(78, 71, 350)	3	(100, 17, 320)

Table 6.2 Initial and Final Route Points

Area 1					
Route	Node	From (X,Y,Z)	Node	To (X,Y,Z)	
1	1	(7, 3, 270)	86	(87, 124, 310)	
2	31	(11, 45, 280)	96	(135, 135, 360)	

Area 2					
Route	Node	From (X,Y,Z)	Node	To (X,Y,Z)	
1	3	(26, 4, 350)	81	(118, 111, 310)	
2	35	(11, 50, 300)	84	(128, 114, 320)	

Table 6.3 Route Cases

Case	Area	Route	Sensor Set
1	1	1	1
2	1	2	1
3	1	1	2
4	1	2	2
5	2	1	1
6	2	2	1
7	2	1	2
8	2	2	2

The initial point and the destination point are placed in the low elevation array with their node number within that array given in Table 6.2. Except for the initial and destination nodes, the set of high and low elevation nodes for an area is determined solely on elevation. They remain constant for all scenarios. Table 6.4 indicates 106 low elevation nodes and Table 6.5 indicates 94 high elevation nodes. Tables 6.6 and 6.7 give the exposure values of these nodes for the first set of sensors. These values will change with each sensor deployment and the number of sensors. The first entry in Table 6.6 corresponds to the first entry in Table 6.4 with the other values corresponding in the order given. Likewise, Table 6.7 entries correspond to the entries in Table 6.5 in the same manner. The data contained in these four tables provide the basic information required for the route selection.

The results of the route selection process for the first case is given in Table 6.8. The node linkage is from node *i* to node *j* with the

Table 6.4. Low Elevation Node Points

X-COORDINATE	7	138	128	3	112	100	68	81	41	56
Y-COORDINATE	3	8	8	5	10	10	11	12	12	13
Z-COORDINATE	270	300	300	300	300	300	290	290	300	290
X-COORDINATE	29	128	113	6	69	141	93	79	25	42
Y-COORDINATE	14	22	23	24	24	25	25	26	27	27
Z-COORDINATE	310	300	300	300	280	300	290	280	300	290
X-COORDINATE	59	121	146	112	68	93	83	53	8	39
Y-COORDINATE	26	31	34	35	38	38	38	38	40	42
Z-COORDINATE	280	300	300	300	280	280	280	280	280	280
X-COORDINATE	23	37	55	11	21	68	83	93	112	145
Y-COORDINATE	43	47	49	45	50	51	52	54	56	59
Z-COORDINATE	280	280	280	280	280	280	280	280	300	300
X-COORDINATE	127	84	94	67	1	25	56	128	113	143
Y-COORDINATE	59	63	63	63	64	64	65	66	66	68
Z-COORDINATE	310	290	290	290	300	300	290	300	300	300
X-COORDINATE	35	94	144	134	8	30	42	68	53	83
Y-COORDINATE	64	76	76	76	77	77	81	83	83	83
Z-COORDINATE	300	300	300	310	340	310	300	300	300	300
X-COORDINATE	108	92	150	30	44	111	55	66	124	8
Y-COORDINATE	89	85	91	91	93	94	95	97	98	98
Z-COORDINATE	330	300	360	330	310	330	300	300	350	350
X-COORDINATE	53	94	150	106	45	56	73	85	56	106
Y-COORDINATE	98	99	105	105	106	106	107	111	113	114
Z-COORDINATE	300	300	360	330	330	320	300	300	300	310
X-COORDINATE	7	145	122	16	16	97	11	113	57	123
Y-COORDINATE	117	119	119	120	122	124	127	128	128	129
Z-COORDINATE	300	340	330	300	300	310	300	330	330	330
X-COORDINATE	86	91	147	75	32	23	14	25	83	38
Y-COORDINATE	129	129	132	135	135	135	127	141	143	144
Z-COORDINATE	300	300	330	310	310	300	300	300	300	300
X-COORDINATE	96	53	146	65	106	124				
Y-COORDINATE	145	146	146	147	149	150				
Z-COORDINATE	300	300	320	300	300	320				

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Table 6.5. High Elevation Node Points

X-COORDINATE	32	46	67	121	149	13	115	17	94	75
Y-COORDINATE	3	3	3	3	3	4	5	5	5	6
Z-COORDINATE	330	310	300	310	330	400	310	400	310	300
X-COORDINATE	12	90	31	47	18	64	147	100	127	90
Y-COORDINATE	16	16	17	18	18	18	20	24	30	31
Z-COORDINATE	330	300	310	300	330	290	310	300	320	290
X-COORDINATE	11	47	21	35	124	115	141	105	105	116
Y-COORDINATE	32	32	35	37	39	42	42	45	46	49
Z-COORDINATE	290	290	300	290	330	330	330	330	320	330
X-COORDINATE	140	129	38	27	66	48	82	10	83	51
Y-COORDINATE	53	54	56	57	55	59	59	60	70	70
Z-COORDINATE	330	330	300	300	290	300	290	310	300	300
X-COORDINATE	66	8	32	17	113	122	104	139	90	105
Y-COORDINATE	71	72	74	74	75	75	75	75	80	80
Z-COORDINATE	300	330	310	330	340	330	330	310	310	340
X-COORDINATE	115	8	33	17	125	47	142	135	22	104
Y-COORDINATE	83	87	88	89	90	90	90	97	99	99
Z-COORDINATE	350	350	330	350	370	310	390	400	350	330
X-COORDINATE	142	115	47	32	61	105	135	9	142	116
Y-COORDINATE	99	101	104	104	105	106	107	107	108	109
Z-COORDINATE	400	350	330	350	320	330	350	350	400	350
X-COORDINATE	25	35	65	49	77	135	140	77	27	67
Y-COORDINATE	113	115	116	116	118	122	124	127	127	128
Z-COORDINATE	350	350	330	340	320	350	350	320	350	330
X-COORDINATE	103	48	41	2	104	44	127	49	64	77
Y-COORDINATE	129	129	130	131	137	137	137	137	138	138
Z-COORDINATE	330	350	350	380	330	340	340	340	330	310
X-COORDINATE	3	140	115	17						
Y-COORDINATE	143	143	144	148						
Z-COORDINATE	380	330	330	340						

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Table 6.6. Exposure Values for Low Elevation Nodes

0.000	.697	.825	.672	1.039	1.160	1.381	1.339	1.405	1.440
1.382	.526	1.217	1.380	1.612	0.000	1.465	1.595	1.587	1.675
1.711	0.000	0.000	1.390	1.866	1.666	1.766	1.892	0.000	1.275
0.000	.762	1.400	0.000	0.000	2.095	1.984	1.283	1.624	.520
1.404	2.118	1.970	0.000	0.000	1.477	2.347	.629	1.688	.537
2.300	2.066	0.000	0.000	1.315	1.590	1.710	2.459	2.526	2.268
1.263	2.134	0.000	1.555	1.753	1.811	2.582	2.452	1.579	1.375
2.264	2.090	0.000	1.874	2.594	2.548	1.601	1.480	1.596	1.832
0.000	0.000	.950	0.000	0.000	.647	0.000	1.623	1.494	1.457
.619	.609	.310	0.000	0.000	0.000	0.000	0.000	0.000	0.000
.506	0.000	.301	0.000	.530	.424				

Table 6.7. Exposure Values for High Elevation Nodes

1.214	1.253	1.149	.836	.486	1.122	.932	1.167	1.129	1.265
1.310	1.345	1.454	1.526	1.390	1.520	0.000	1.380	.214	1.589
1.107	1.777	1.685	1.815	.625	1.433	1.034	1.610	1.622	1.494
1.142	1.332	2.135	2.060	2.213	2.234	2.055	.637	2.203	2.395
2.421	.629	2.317	.684	1.739	.665	1.894	0.000	2.149	1.697
1.731	1.352	2.455	1.445	1.185	2.574	1.259	1.384	1.513	1.925
1.256	1.732	2.607	1.598	2.509	1.887	1.366	.818	1.235	1.690
1.547	1.630	1.535	2.505	1.445	.827	1.366	1.386	1.492	1.442
1.766	1.519	1.519	1.222	1.096	.878	1.325	.863	.791	0.000
1.144	.706	.967	.786						

Table 6.8. NODE LINKAGE FOR ROUTE

FROM	EASTING	NORTHING	TO	PENALTY	EASTING	NORTHING
1	490	7210	4	153	210	7630
4	210	7630	-8	263	1190	7350
-8	1190	7350	11	164	2030	7980
11	2030	7980	9	207	2870	7840
9	2870	7840	10	145	3920	7910
10	3920	7910	15	188	4830	8680
15	4830	8680	27	177	5810	9660
27	5810	9660	20	266	6510	9660
20	6510	9660	-29	278	7350	10220
-29	7350	10220	39	247	7840	10920
39	7840	10920	49	242	7910	11620
49	7910	11620	48	150	8960	11620
48	8960	11620	-48	58	9730	12250
-48	9730	12250	53	202	10080	12320
53	10080	12320	63	72	10500	13370
63	10500	13370	73	27	10500	14350
73	10500	14350	82	57	10430	15330
82	10430	15330	93	96	10290	16240
93	10290	16240	103	124	10220	17220
103	10220	17220	83	158	8540	15330
83	8540	15330	88	228	7910	15960
88	7910	15960	-85	234	7280	16590
-85	7280	16590	-50	44	5390	16660
-50	5390	16660	86	97	6090	15680

Table 6.9. Node Linkage

NODE NO.	1	TOTAL LINKS	4				
X,Y,Z COORDINATE	7,	3,	270				
LINKED TO	4	-6	-8	-11			
EXPOSURE	152	311	263	160			
WEIGHTED	153	312	264	322			
NODE NO.	4	TOTAL LINKS	5				
X,Y,Z COORDINATE	3,	5,	300				
LINKED TO	14	-6	-11	-2	-15		
EXPOSURE	172	311	257	262	168		
WEIGHTED	146	312	516	263	338		
NODE NO.	-2	TOTAL LINKS	6				
X,Y,Z COORDINATE	17,	5,	400				
LINKED TO	11	-6	-11	-15	-1	-13	
EXPOSURE	163	311	197	198	166	145	
WEIGHTED	164	624	198	398	167	252	
NODE NO.	11	TOTAL LINKS	6				
X,Y,Z COORDINATE	25,	14,	310				
LINKED TO	9	19	20	-13	-1	-15	
EXPOSURE	206	215	167	294	266	281	
WEIGHTED	207	216	336	590	534	564	
NODE NO.	9	TOTAL LINKS	5				
X,Y,Z COORDINATE	41,	12,	300				
LINKED TO	10	-14	-2	-13	-1		
EXPOSURE	144	277	246	253	254		
WEIGHTED	145	278	494	254	510		
NODE NO.	10	TOTAL LINKS	7				
X,Y,Z COORDINATE	56,	13,	290				
LINKED TO	7	21	15	20	-16	-14	-2
EXPOSURE	244	214	187	199	284	308	276
WEIGHTED	245	430	188	200	285	309	554
NODE NO.	15	TOTAL LINKS	7				
X,Y,Z COORDINATE	65,	24,	280				
LINKED TO	18	21	7	25	8	27	-16
EXPOSURE	239	246	285	234	248	176	342
WEIGHTED	241	247	572	470	492	177	626
NODE NO.	27	TOTAL LINKS	7				
X,Y,Z COORDINATE	83,	36,	280				
LINKED TO	26	18	37	25	17	36	-20
EXPOSURE	285	231	257	235	272	209	349
WEIGHTED	266	464	2580	472	546	2100	720
NODE NO.	26	TOTAL LINKS	7				
X,Y,Z COORDINATE	93,	35,	280				
LINKED TO	17	27	18	-20	-28	-23	-18
EXPOSURE	216	209	159	278	301	277	202
WEIGHTED	424	420	320	558	302	278	406
NODE NO.	-29	TOTAL LINKS	7				
X,Y,Z COORDINATE	105,	46,	320				
LINKED TO	39	24	38	-28	-26	-30	-20
EXPOSURE	246	218	161	359	293	295	178
WEIGHTED	247	438	324	720	588	296	358
NODE NO.	39	TOTAL LINKS	5				
X,Y,Z COORDINATE	112,	56,	300				
LINKED TO	49	41	-30	-28	-26		
EXPOSURE	241	172	346	289	253		
WEIGHTED	242	346	694	580	508		
NODE NO.	49	TOTAL LINKS	6				
X,Y,Z COORDINATE	113,	66,	300				
LINKED TO	48	41	-45	-46	-47	-50	
EXPOSURE	78	171	371	187	310	287	
WEIGHTED	158	344	372	188	622	288	

Table 6.9. (cont'd.)

NODE NO.	46	TOTAL LINKS	8						
X,Y,Z COORDINATE	126.	66.	300						
LINKED TO	41	54	50	-46	-32	-48	-45	-31	
EXPOSURE	264	81	77	204	255	57	273	167	
WEIGHTED	530	52	156	205	520	58	546	376	
NODE NO.	-49	TOTAL LINKS	4						
X,Y,Z COORDINATE	139.	75.	310						
LINKED TO	53	54	50	-55					
EXPOSURE	150	114	125	237					
WEIGHTED	252	230	252	236					
NODE NO.	53	TOTAL LINKS	5						
X,Y,Z COORDINATE	144.	76.	300						
LINKED TO	50	54	63	-57	-55				
EXPOSURE	153	88	71	253	215				
WEIGHTED	302	89	72	254	216				
NODE NO.	63	TOTAL LINKS	5						
X,Y,Z COORDINATE	150.	91.	360						
LINKED TO	73	-57	-61	-55	-58				
EXPOSURE	25	299	283	176	235				
WEIGHTED	27	630	284	354	472				
NODE NO.	73	TOTAL LINKS	7						
X,Y,Z COORDINATE	150.	105.	360						
LINKED TO	82	-69	-61	-67	-58	-57	-55		
EXPOSURE	56	322	312	266	270	241	187		
WEIGHTED	57	323	313	534	542	242	188		
NODE NO.	82	TOTAL LINKS	5						
X,Y,Z COORDINATE	145.	115.	340						
LINKED TO	93	-77	-65	-76	-67				
EXPOSURE	95	214	288	161	421				
WEIGHTED	96	215	289	162	444				
NODE NO.	93	TOTAL LINKS	4						
X,Y,Z COORDINATE	147.	132.	330						
LINKED TO	103	-77	-92	-76					
EXPOSURE	61	273	154	179					
WEIGHTED	124	548	155	360					
NODE NO.	103	TOTAL LINKS	6						
X,Y,Z COORDINATE	145.	146.	320						
LINKED TO	90	83	-92	-87	-77	-76			
EXPOSURE	171	98	170	231	216	210			
WEIGHTED	344	198	342	464	217	211			
NODE NO.	63	TOTAL LINKS	5						
X,Y,Z COORDINATE	122.	119.	330						
LINKED TO	90	88	-70	-76	-67				
EXPOSURE	245	227	280	172	234				
WEIGHTED	246	228	281	345	470				
NODE NO.	88	TOTAL LINKS	5						
X,Y,Z COORDINATE	115.	126.	330						
LINKED TO	90	80	-81	-85	-87				
EXPOSURE	310	198	341	233	229				
WEIGHTED	622	398	342	234	460				
NODE NO.	-85	TOTAL LINKS	12						
X,Y,Z COORDINATE	104.	137.	330						
LINKED TO	91	90	80	79	78	-81	-87	-90	-78
LINKED TO	-70	-75	130	242	230	151	335	251	42
EXPOSURE	115	254	130	242	230	151	335	251	42
EXPOSURE	277	183							
WEIGHTED	232	510	242	243	462	304	336	504	44
WEIGHTED	278	368							
NODE NO.	-90	TOTAL LINKS	5						
X,Y,Z COORDINATE	77.	136.	310						
LINKED TO	91	86	-78	-89	-80				
EXPOSURE	134	96	203	243	290				
WEIGHTED	135	97	204	244	292				

corresponding penalty associated with this pairing. The easting and northing values are the number of meters from the southwest corner of the area. This corner is the standard position for reference on a map. Knowing the southwest corner of the actual map area being analyzed, the nodes can be positioned on the map by finding the point X meters easting and Y meters northing from the southwest corner. Table 6.9 contains the neighborhood nodes for each node along the route. Three data items are provided: The nodes are listed on the third line, the unweighted exposure value pertaining to that node is listed on the fourth line, and the final weighted penalty for the node is given on the fifth line.

Figure 6.1 shows the position of the sensors and the resulting route for the first case. The route avoids the air defense sensors by traveling east before turning north. The destination point is approached from an easterly direction.

Figures 6.2 through 6.8 are the resulting routes for the cases listed in Table 6.3. In each Figure the location of the sensors are shown. The terrain in Figures 6.1 through 6.4 is flat to moderately hilly. There is a valley that proceeds from the southwest to the northeast through the center of this terrain. The rough terrain is located to the southeast and east. A large flat-top hill is located in the northwest.

The terrain in the second area is rougher (Case 5 through 8). There is a prominent ridge running from the southeast to the center of the area. There are valleys on each side of this ridgeline that join in the northwest. In Figures 6.5 and 6.7, the route selection was difficult with the sensors located in the northern and central areas. When the sensors were located on top of the ridge and to the south,

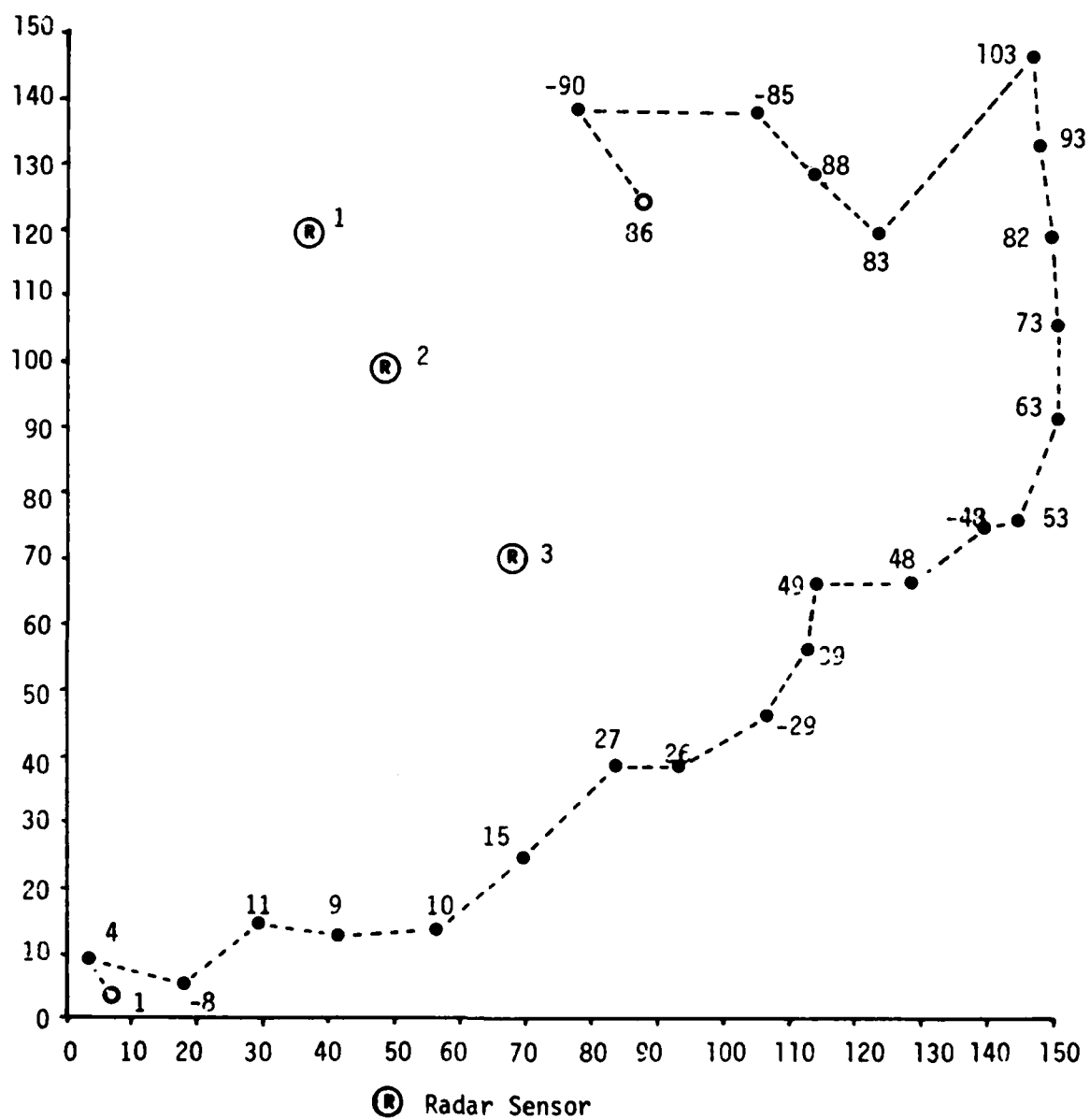


Figure 6.1. Case 1 - A1, R1, S1.

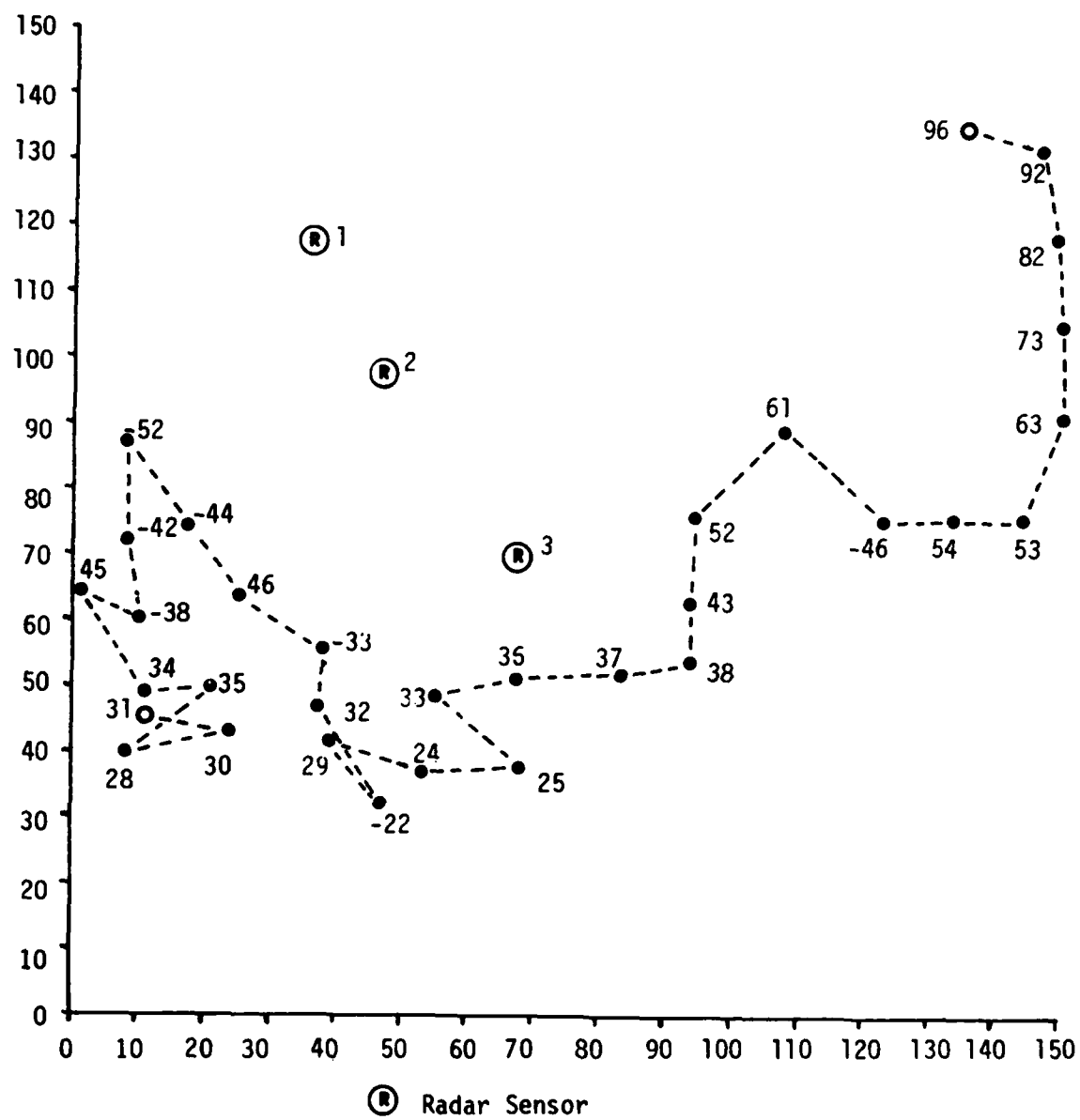


Figure 6.2. Case 2 - A1, R2, S1.

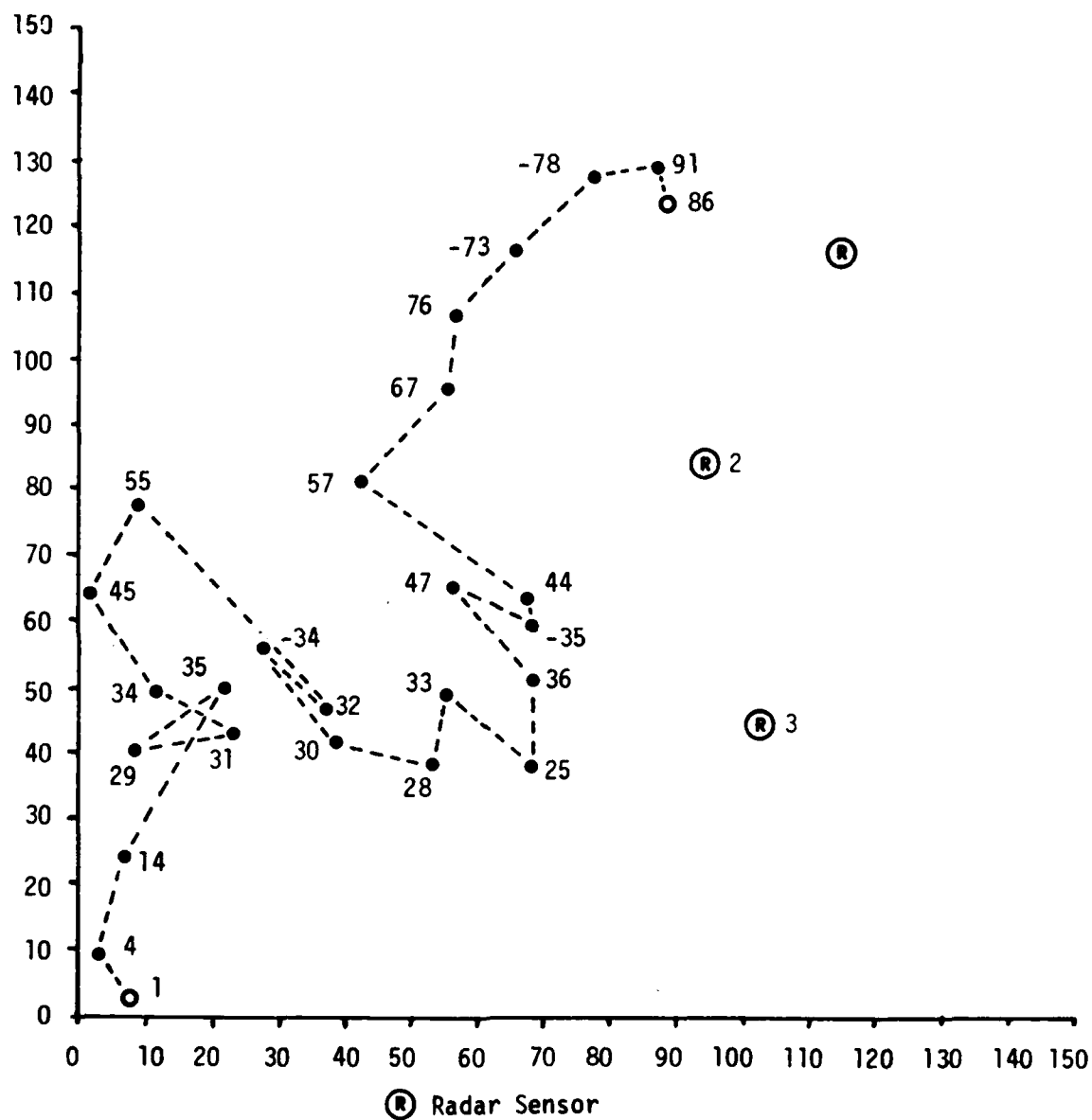
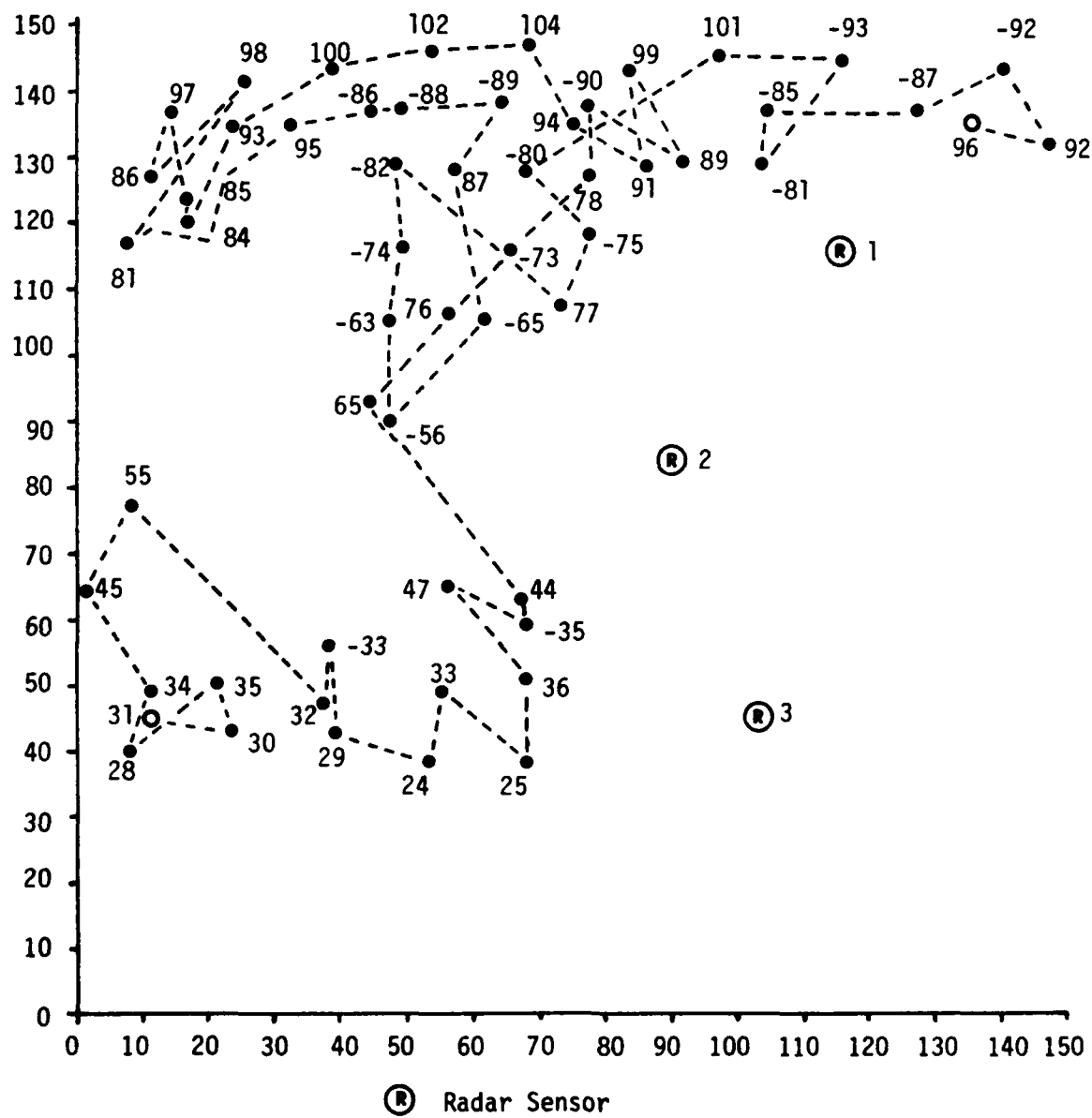


Figure 6.3. Case 3 - A1, R1, S2.



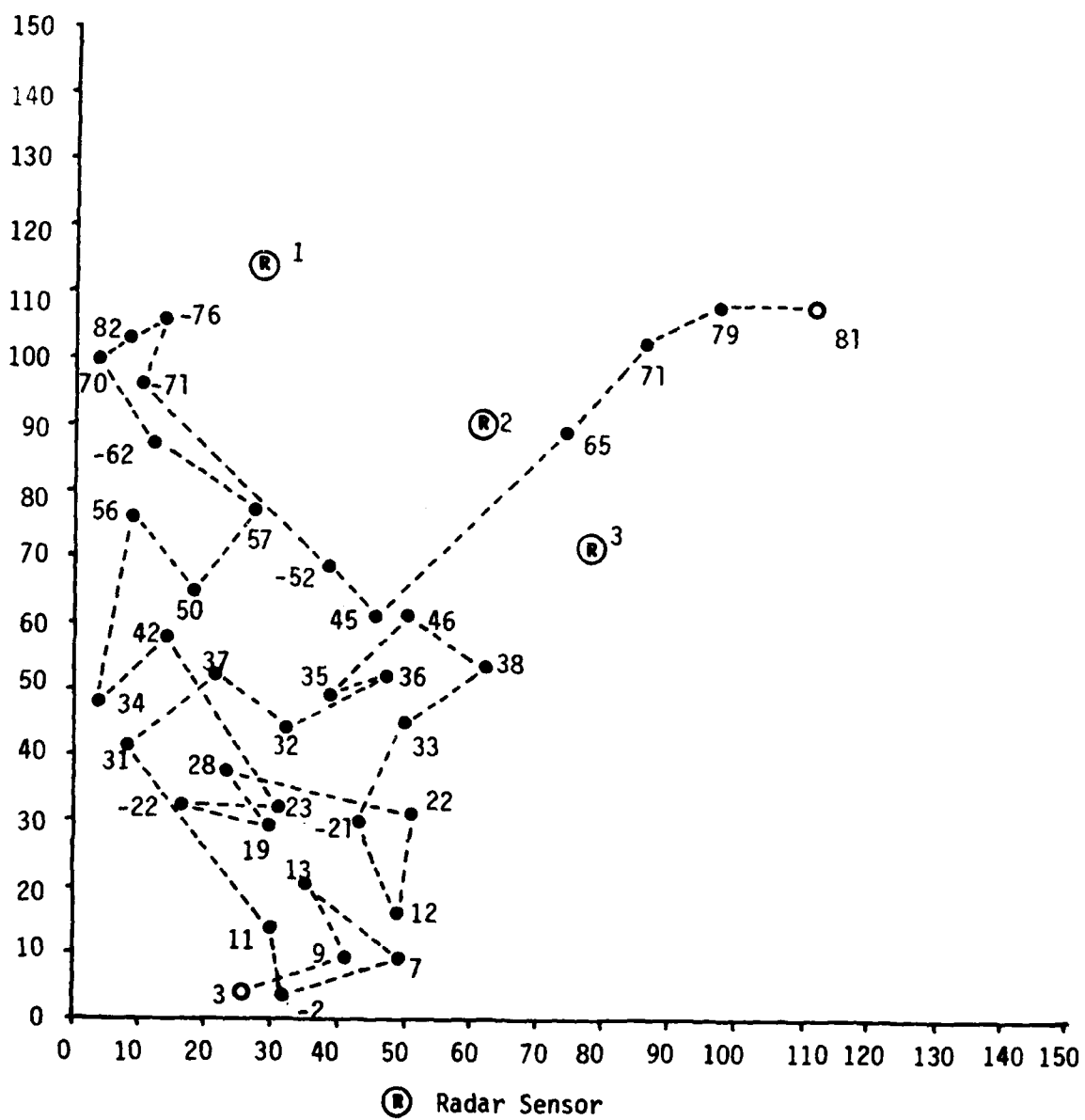


Figure 6.5. Case 5 - A2, R1, S1.

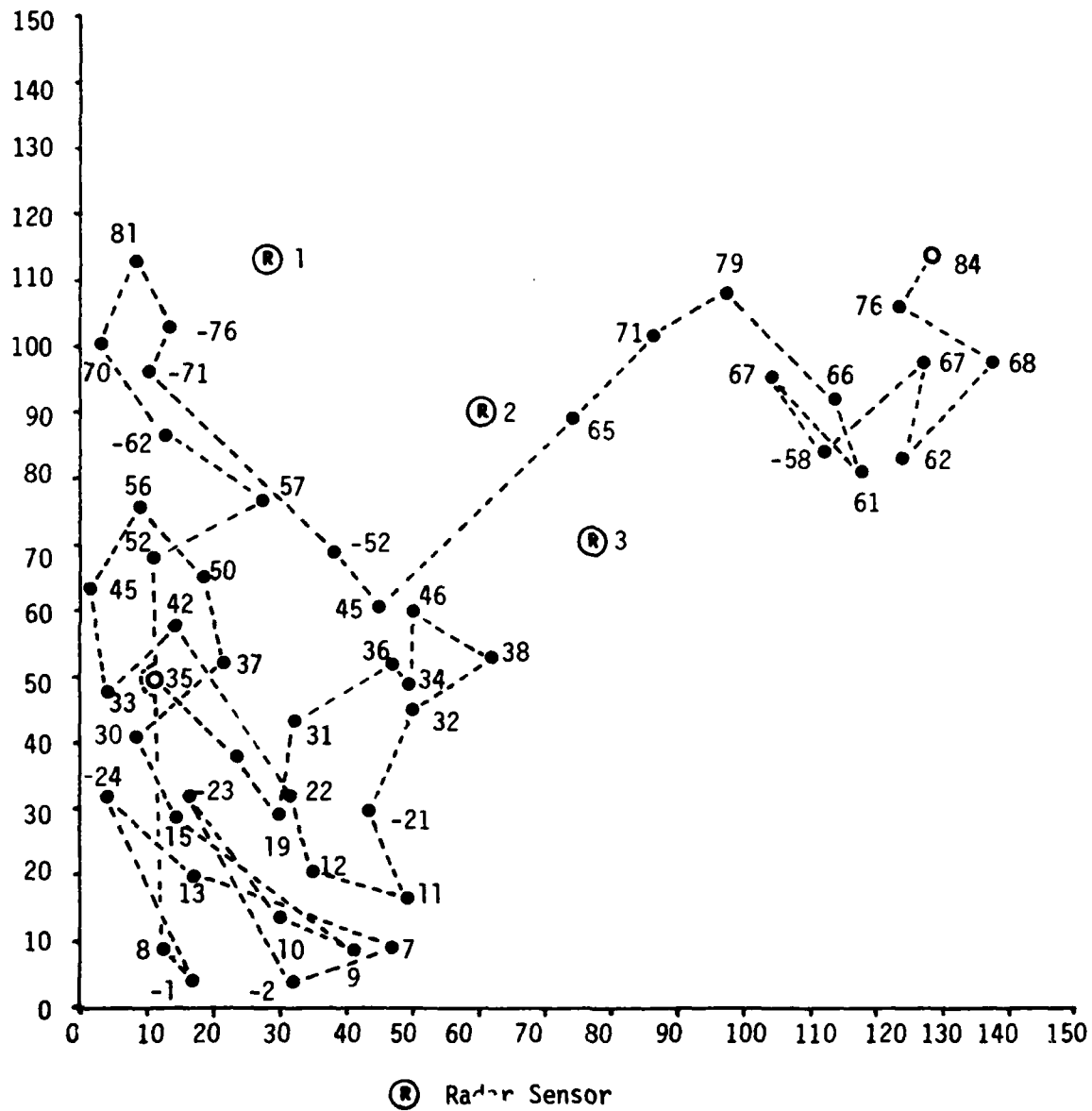


Figure 6.6. Case 6 - A2, R2, S1.

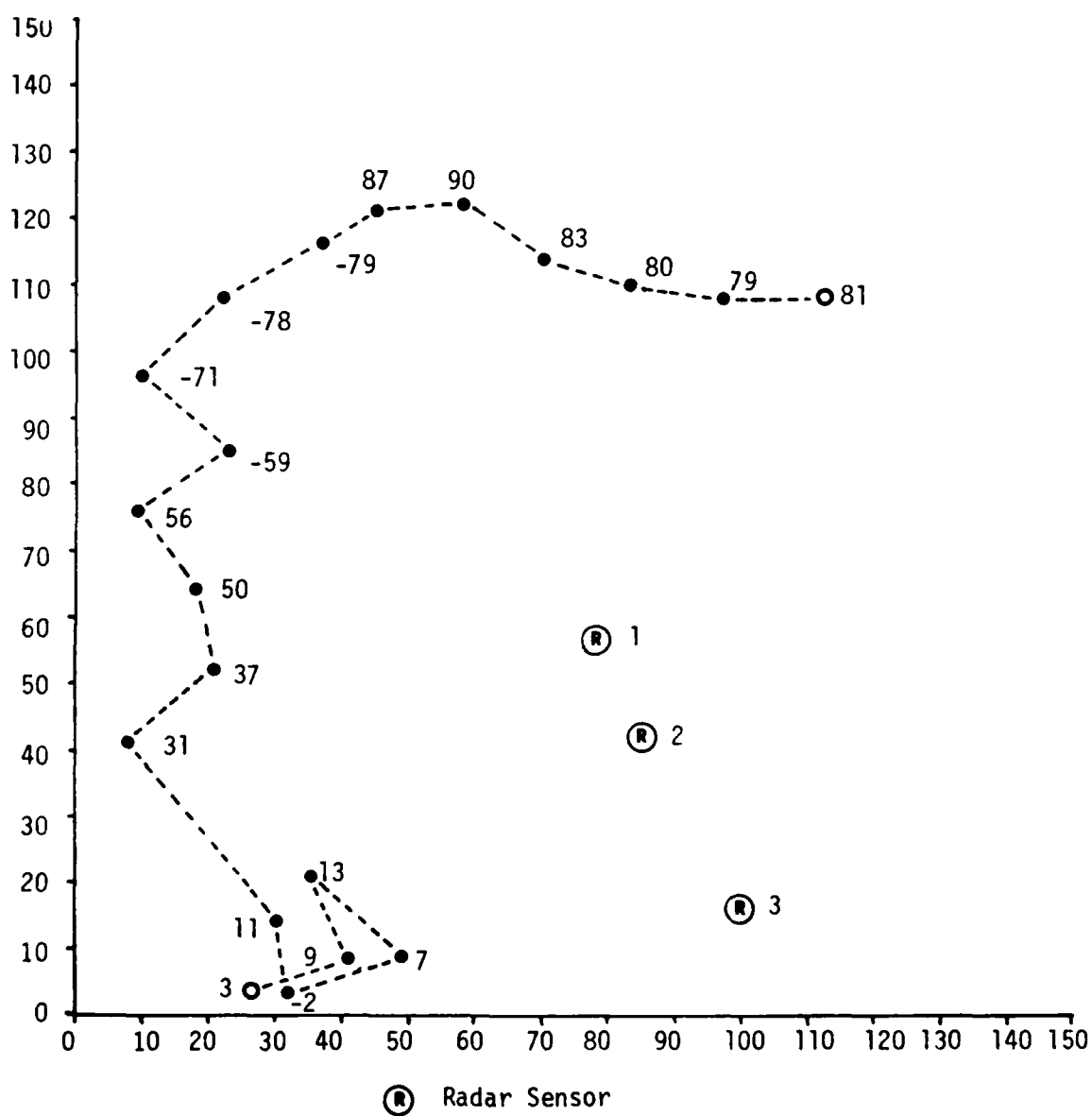


Figure 6.7. Case 7 - A2, R1, S2.

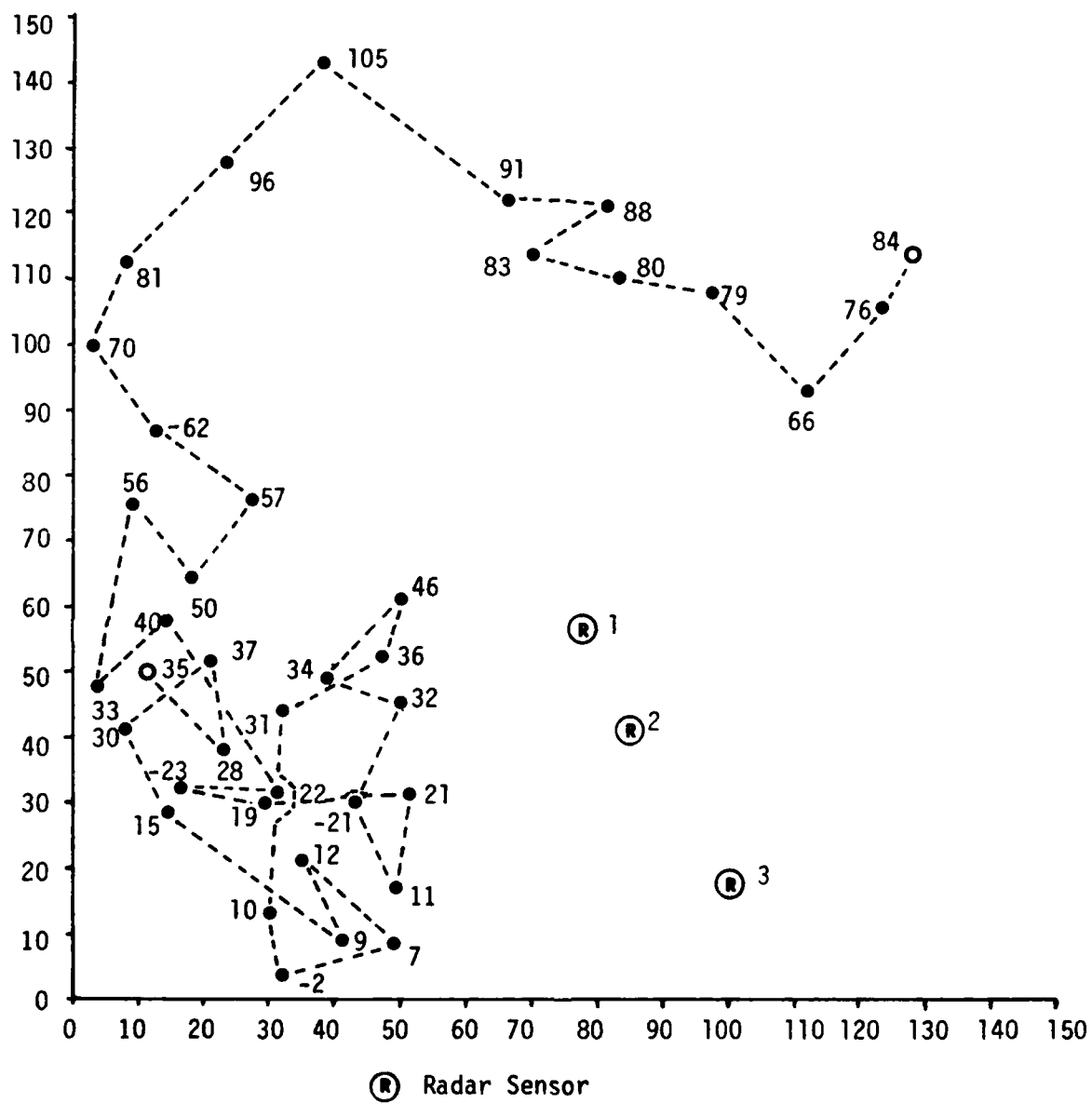


Figure 6.8. Case 8 - A2, R2, S2.

the routes selected follow the base of this ridge (Figures 6.6 and 6.8).

6.3. Refined Routes

These initial routes shown in Figures 6.1 through 6.8 were refined and the new routes are shown in those cases where improvement could be achieved. For case one, the refinement process accepted the initial results as final.

In the other cases improvement was achieved by the refinement process. The improvement in case two occurs at the beginning of the route (Figure 6.9). The route initially headed north and was not able to avoid the air defenses. The model reversed directions and utilized a southern route. The route refinement eliminates the first several nodes to achieve the improvement.

The radars are located in the east for cases three and four. The initial routes are to the north; however, the hilly region in the northwest caused the selection process to change directions and proceeds south. The refinement in case three smoothed the initial portion of the route (Figure 6.10). The destination point in case four is located beyond the line of radars; thus, causing the route selection to double back to avoid the air defenses. There is significant improvement when the route is refined (Figure 6.11).

In area two, the rougher terrain resulted in three of the four routes doubling back significantly. With the radars deployed on the high ground to cover the approach corridors, the route meanders considerably since the model searched for an acceptable low exposure route (Figures 6.5 and 6.6). The selection process finally reached node 45 from which the radars could be breached. Figures 6.12 and 6.13

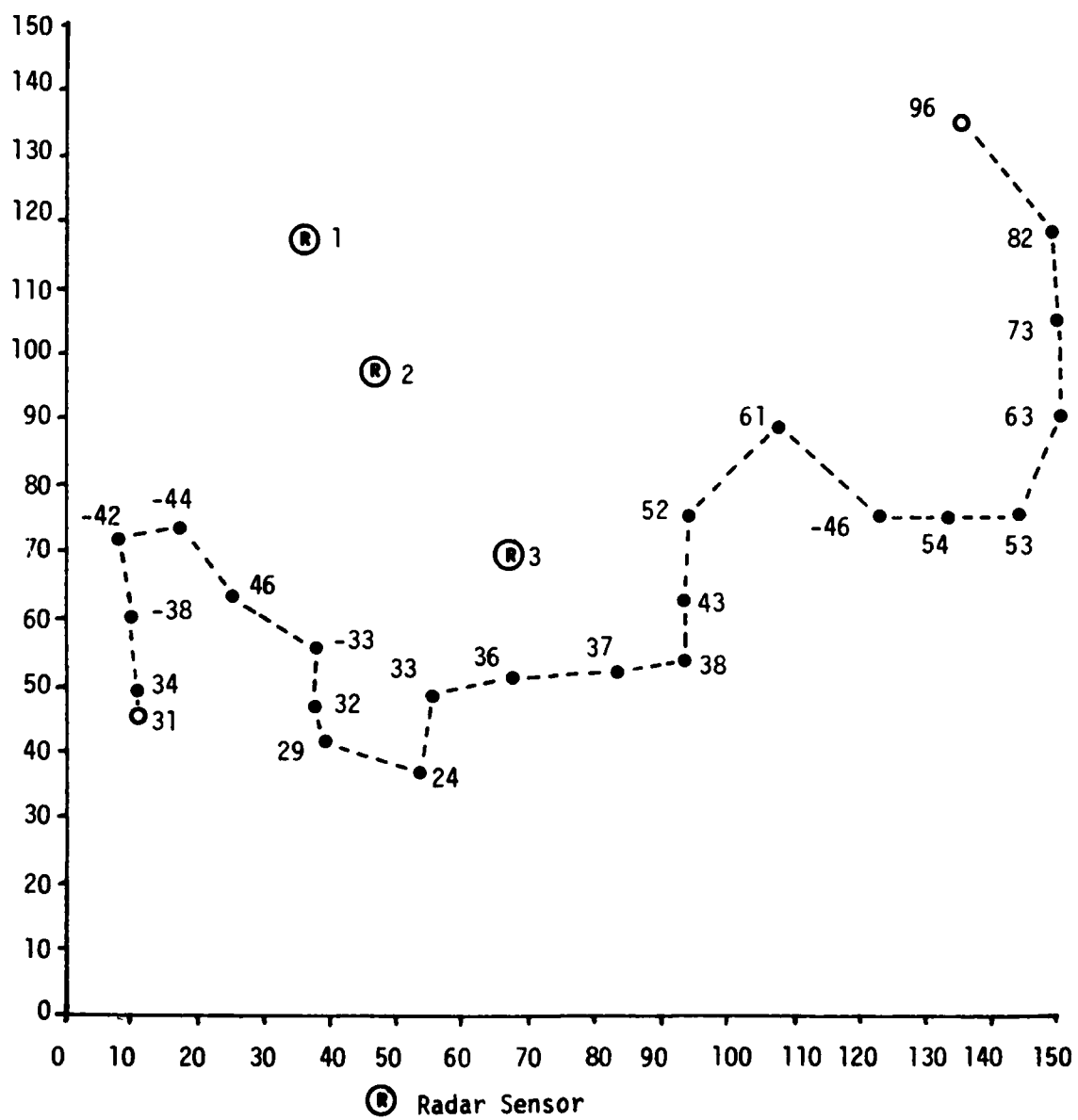


Figure 6.9. Case 2 - Refined Route.

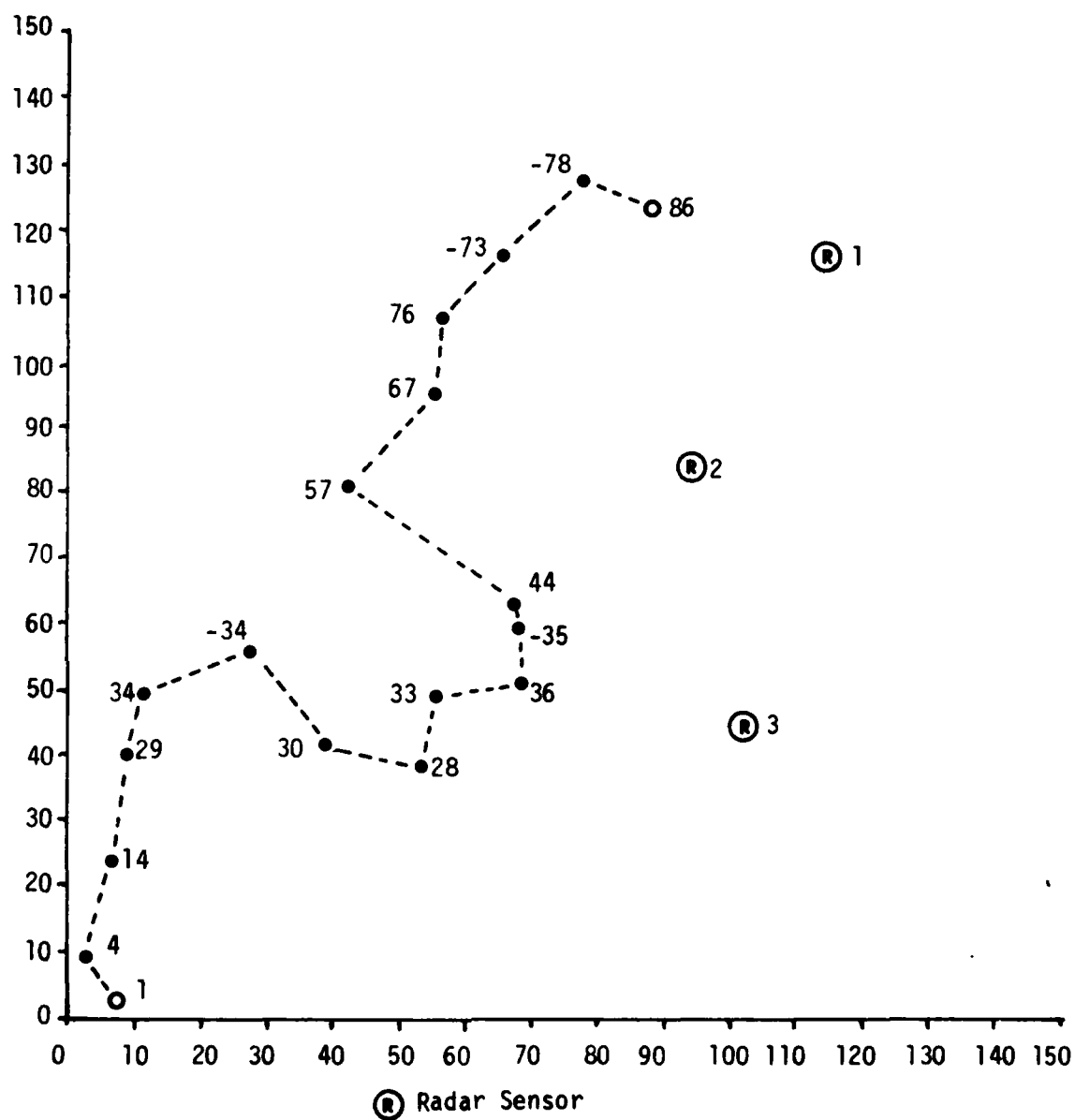


Figure 6.10. Case 3 - Refined Route.

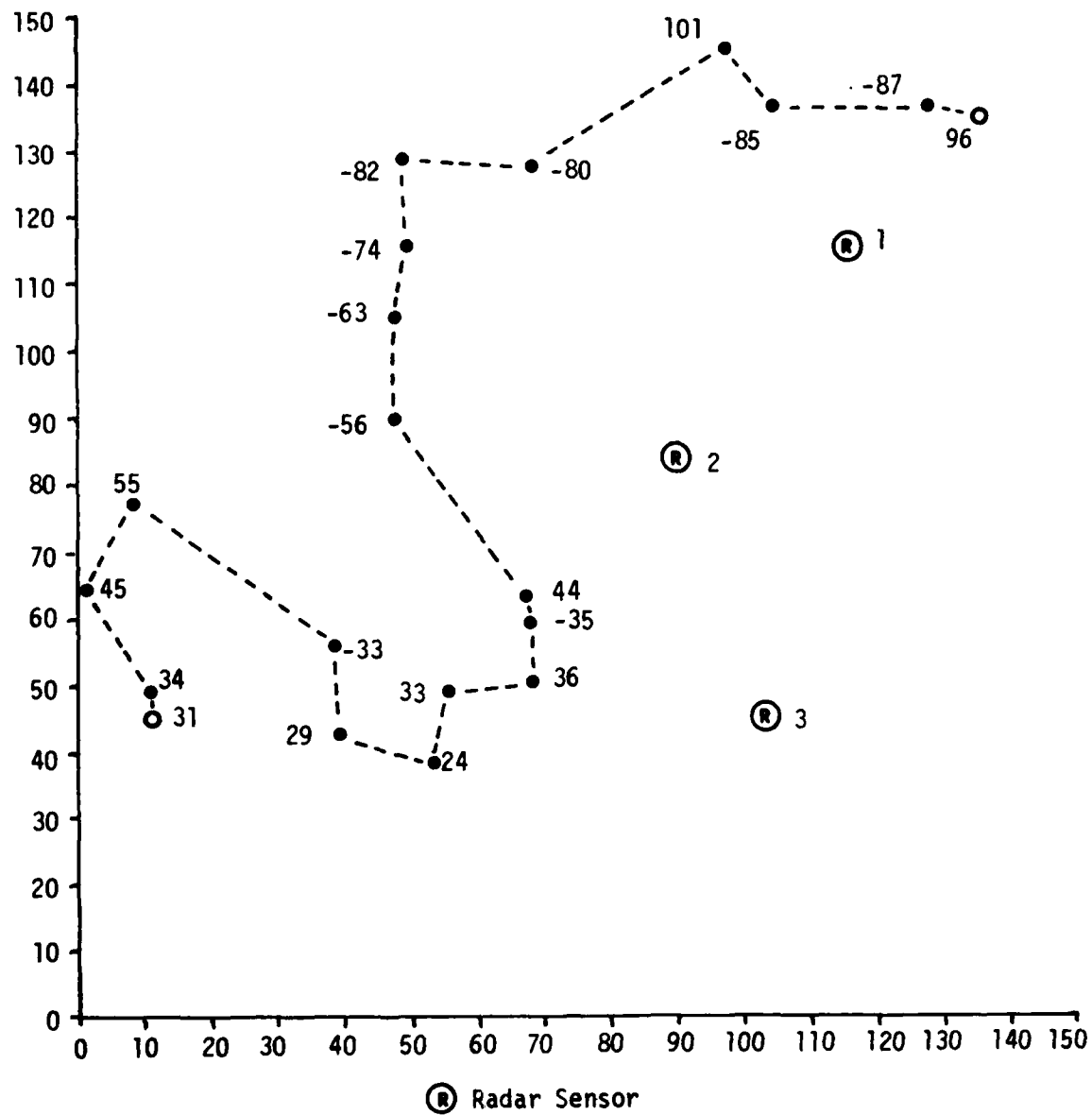


Figure 6.11. Case 4 - Refined Route.

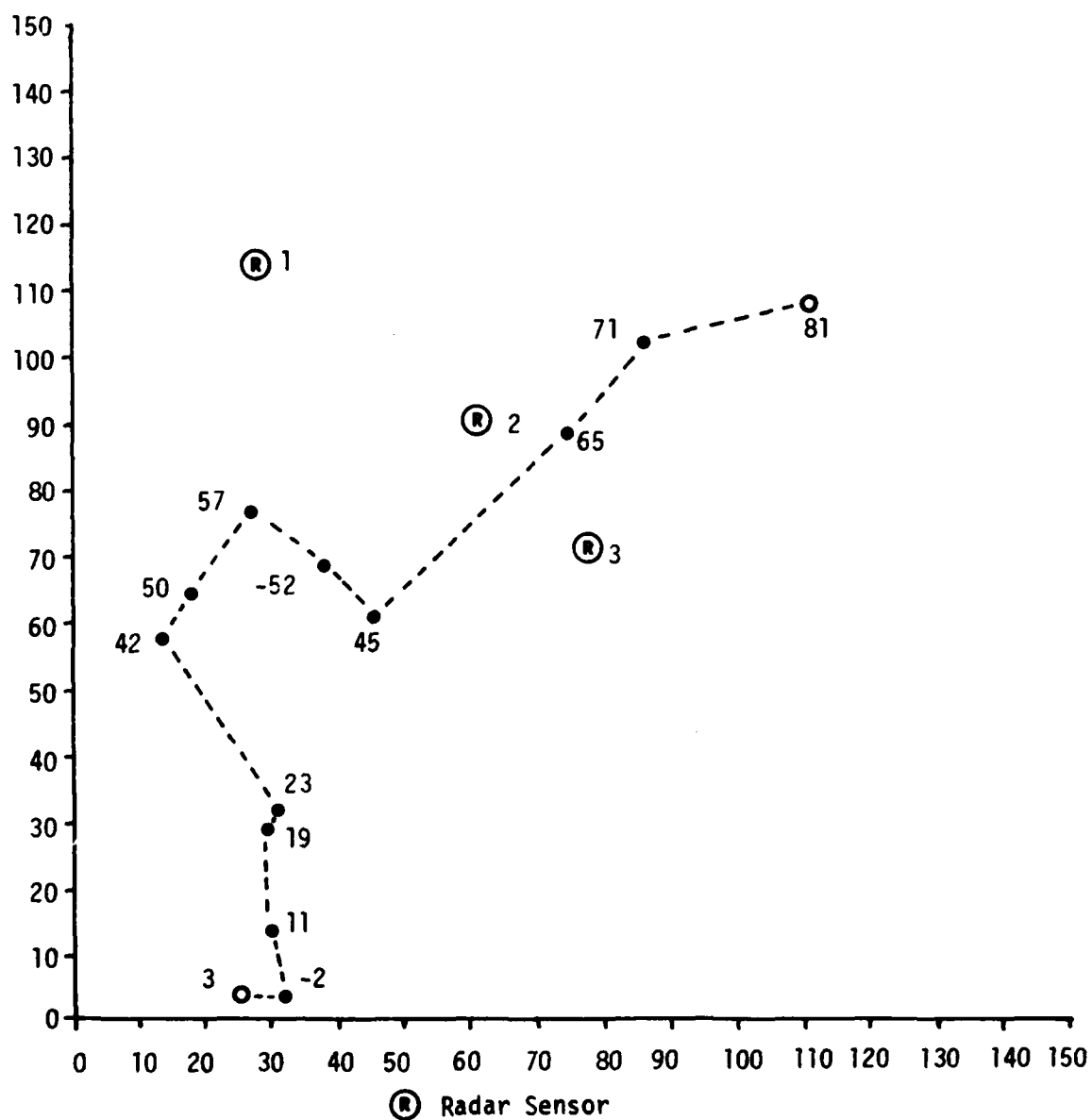


Figure 6.12. Case 5 - Refined Route.

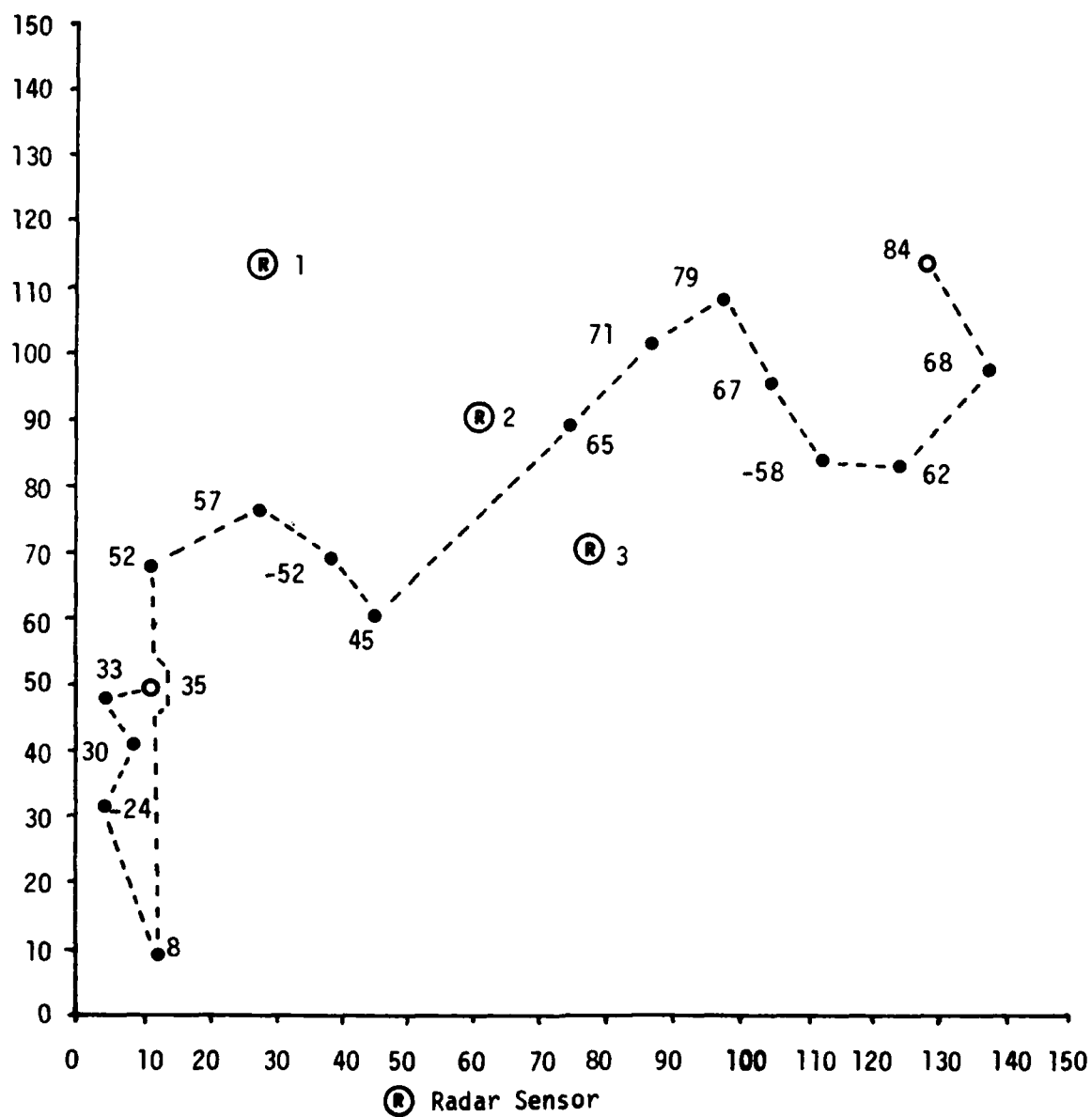


Figure 6.13. Case 6 - Refined Route.

shows considerable route improvement when these routes are refined. Figure 6.13 indicates that the route refinement is not perfect in that there is obvious improvement by proceeding directly from node 35 to node 52.

Case seven was the only route in area two that the initial route was acceptable. Only the first three nodes are eliminated in the refinement. For case eight, the initial node is located in a narrow valley forcing the route selection to proceed south. This direction is towards the air defenses causing the meandering in the route. The refinement caused the route selection to be across the valley entrance slope to achieve an acceptable route. The routes in Figures 6.14 and 6.15 are mostly along the base of the ridge. In Table 6.10 is a summary of the improvements in terms of nodes traversed.

Table 6.10 Route Improvement (Node Traversed)

Case	Initial	Final
1	25	25
2	32	24
3	26	18
4	57	20
5	37	13
6	51	17
7	20	16
8	39	15

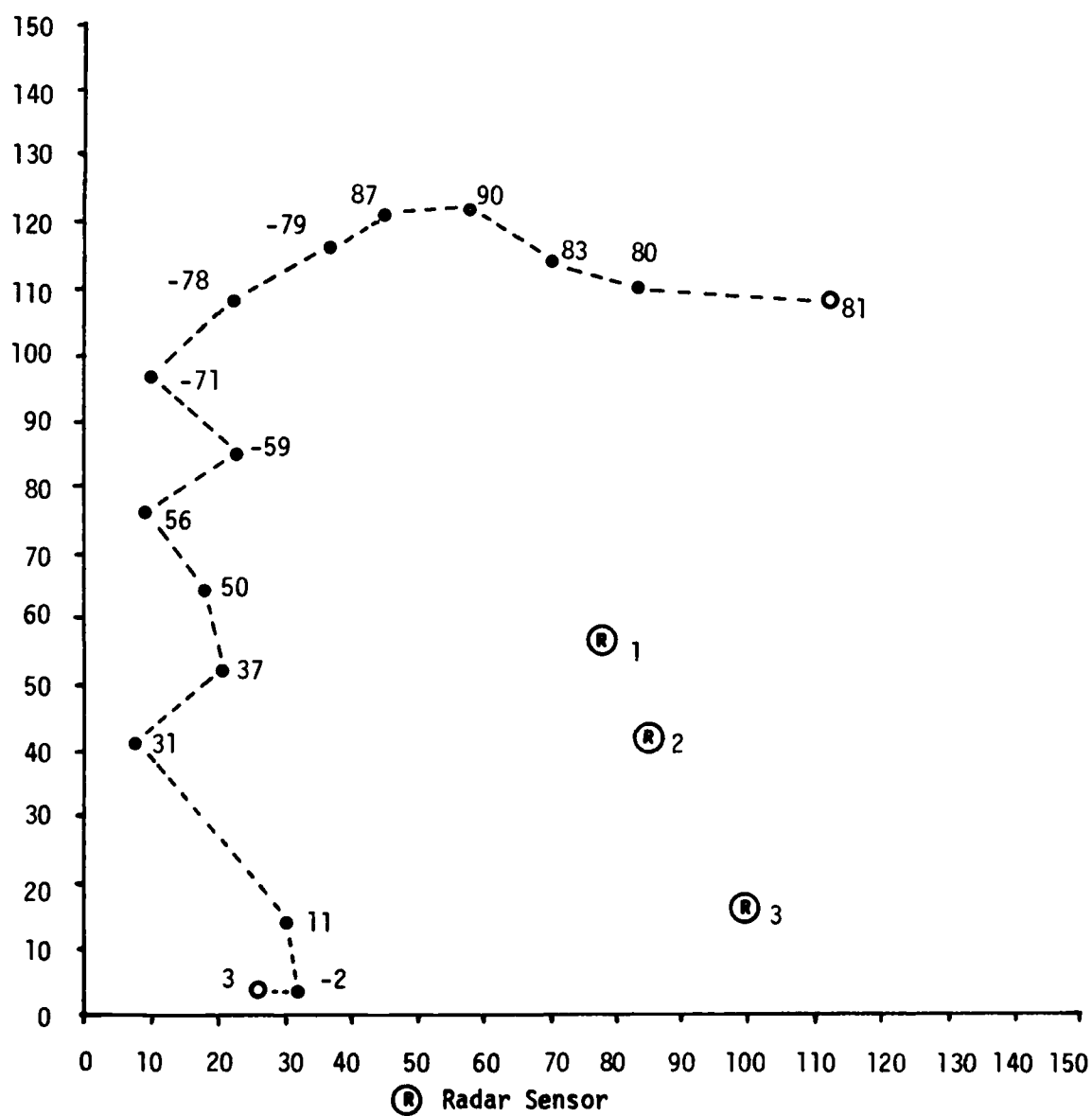


Figure 6.14. Case 7 - Refined Route.

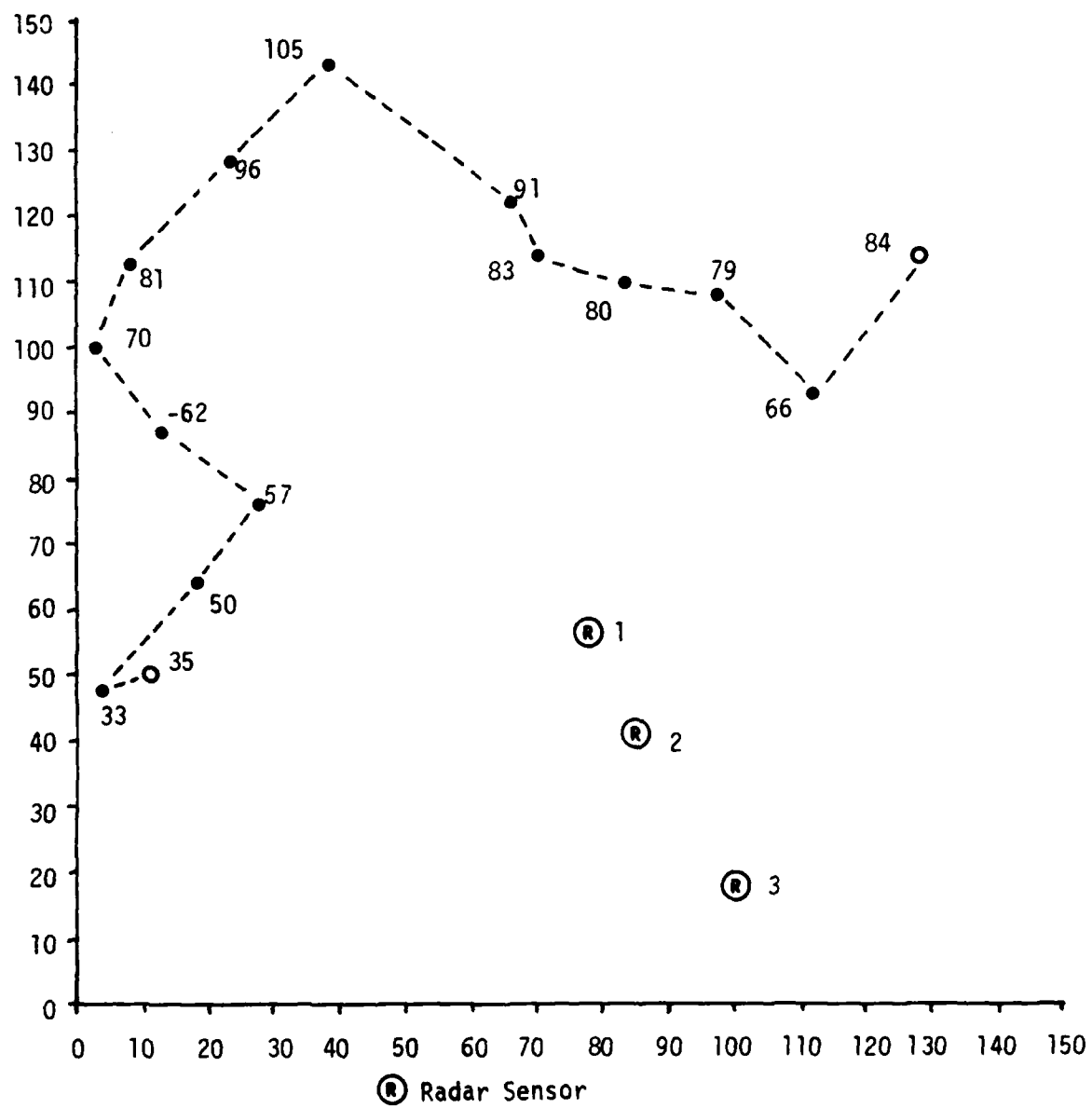


Figure 6.15. Case 8 - Refined Route.

6.4 Large Area Analysis

Several size terrain areas were utilized to evaluate the model's performance. The initial point was held constant and the destination and number of sensors were varied. Table 6.11 gives the location of the sensors and the size area where they were utilized. The areas ranged from 20 by 20 km to 35 by 35 km. The elevation varied from 270 to 610 meters for the 20 by 20 km case and varied from 270 to 850 meters for the 35 by 35 km cases. The limiting factor in the area size is computer core capacity.

The southwest corner of each area is the same. The larger size areas are obtained by increasing the x and y distance from this corner. The test area discussed in section 6.2 is the southwest 10 x 10 km sector of these larger areas. As one travels from the southwest to the northeast the terrain becomes progressively rougher. Thus, the routes were selected to travel this same direction. They begin in the southwest and end in the northeast sector. Since the areas are larger the lethal radius of the systems were increased to 6 km.

The large size of these areas resulted in voluminous output from the model. Therefore, the results are summarized rather than presented in detail as the small areas. The routes developed by the model had the same characteristics of the small areas. The route end points and the sensor deployment determined the smoothness of the route. The routes for all cases would begin fairly straight; however, the deployment of the sensors and terrain roughness would cause meandering of the route when it reached the central area of the 35 by 35 km case. The refinement process eliminated the doubling back as it had done in the small cases.

Table 6.11 Sensor Deployment

20-20 km Area		35-35 km Area	
<u>Sensor</u>	<u>(X,Y,Z)</u>	<u>Sensor</u>	<u>(X,Y,Z)</u>
1	(97, 280, 500)	1	(300, 414, 490)
2	(165, 250, 440)	2	(371, 214, 490)
3	(193, 71, 400)	3	(14, 314, 450)
25-25 km Area		4	(285, 328, 460)
<u>Sensor</u>	<u>(X,Y,Z)</u>	5	(228, 407, 520)
1	(97, 280, 500)	6	(285, 243, 450)
2	(165, 250, 440)	7	(200, 214, 410)
3	(193, 71, 400)	8	(336, 71, 350)
30-30 km Area		9	(364, 288, 530)
<u>Sensor</u>	<u>(X,Y,Z)</u>	10	(97, 280, 500)
1	(97, 280, 500)		
2	(336, 71, 350)		
3	(364, 288, 530)		

Table 6.12 provides an overall summary of the six large cases. The computer processing time for each of the cases indicates that terrain size significantly increases the run times for the model. The 30 by 30 km case, when compared to the 35 by 35 km case of three radars, indicates the deployment and route end points can produce very different results. The initial routes for these two cases are refined to approximately the same size. In all cases the refinement provided an improvement in route performance by reducing the penalty.

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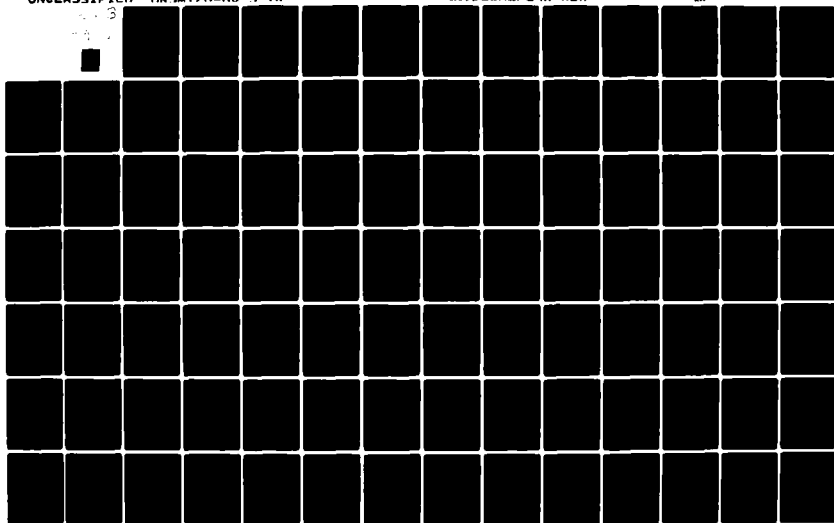
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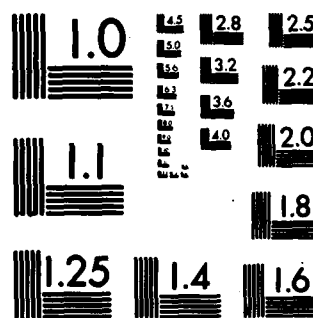
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table 6.12 Large Area Cases

Area	Sensors	Low Nodes	High Nodes	Route Nodes	Penalty	Refined Nodes	Penalty	Run Time (sec)
20-20	3	415	389	63	6996	28	3510	79.5
25-25	3	648	624	218	17498	35	5086	114.1
30-30	3	938	918	458	44499	63	7793	155.1
35-35	3	1289	1258	181	12783	66	5325	187.6
35-35	5	1289	1258	331	29082	86	7097	216.9
35-35	10	1289	1258	466	95154	97	19942	284.3

CHAPTER VII

MODEL VALIDATION

7.1 Introduction

For the model to be of any utility, it must be tested and validated. A comparison is required between a tactician's route analysis and the heuristic model which attempts to approximate that analysis.

The test area has relatively flat terrain through the center region and high ground on the eastern edge and in the northwest corner. The hilly areas are difficult for the model logic to process into a smooth route line that an individual would expect to see for a route.

A tactician planning a route needs to visually perceive the relationship between the route initialization, positions to be avoided, and the final destination. The air defense sensors will be bypassed, if possible, by traveling around these positions outside their effective engagement limits. However, one tactician's ideal route may be another tactician's worst case. The manually produced route is a highly subjective analysis.

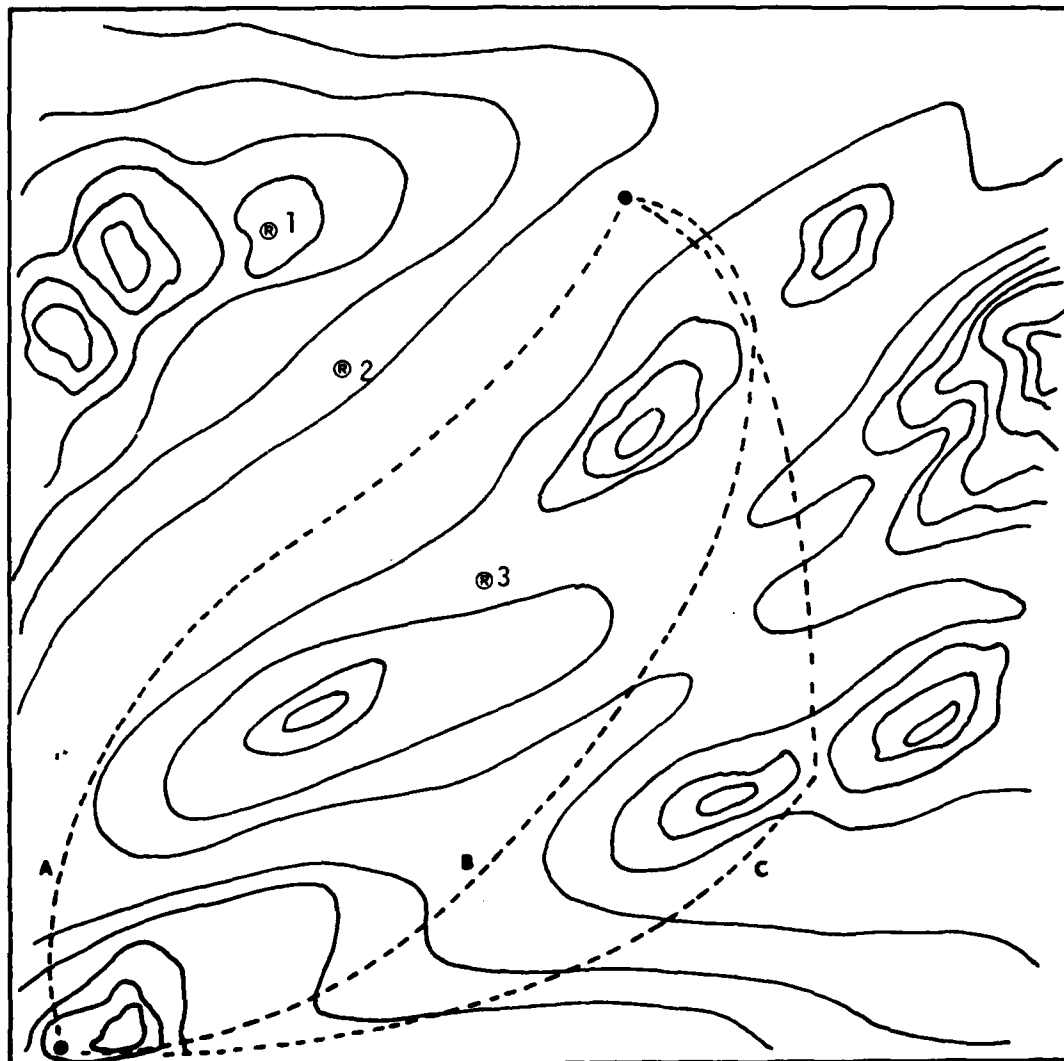
7.2 Manual Route Selection

The development of a route by manual analysis requires studying a topographic map of the appropriate area. The development of a low flying aircraft route dictates the type of information desired: The

location of the air defenses, the valleys, the hill tops, and the built-up areas is important. The information concerning the area is utilized in the route selection to avoid the air defenses and enemy concentrations.

The problem with reading a topographic map is trying to perceive the 3-dimension aspects of the terrain. Ordinarily, relief is shown by contour lines. For level terrain the contour lines are widely spaced whereas rough or hilly terrain will have densely packed contour lines. The rivers and streams give the location of valley floors and lowest points in flat terrain. One method for showing the vertical aspects of the terrain is to draw a profile of the elevation. Along a line between any two points the contour elevations are plotted, from which LOS can be determined and the degree of terrain roughness (see Figure 2.2). For a large area and even a modest number of points this approach is impractical.

Figure 7.1 depicts the terrain area used in the test case and indicates the relative position of the hills and valleys with the sensors. The routes shown in Figure 7.1 were developed by questioning analysts whose expertise is in air defense routing. Providing them with the location of the sensors and the route end points on a topographic map, the routes A, B, and C were chosen. If a direct route is required, route A is proposed since it follows the valley floor and passes midway between two of the sensors. If the sensors are to be avoided, routes B and C are chosen since they utilize the hills as masks and bypass



① Radar Sensor
A,B,C Routes

Figure 7.1. Terrain Area One.

the sensors. Routes B and C are preferred by all the analysts. The question of model validity is whether or not similar routes are produced when the model uses its decision logic.

7.3 Model Route Selection

For development and testing of the model a 10 by 10 km area was selected from the 35 by 35 km data base that is representative of both relatively flat and hilly terrain. In the initial testing, the model would form a circuit through several nodes before returning to the starting node. After these first runs, decision logic was added in the form of weighting as described in Chapter IV. The major piece of information the model considers that the tactician has difficulty in assimilating is the LOS determination. The degree of visibility a node has with the sensors provides a basis upon which a quantitative selection can be made.

To test this hypothesis, the model was run with different levels of information available to the decision logic. With only the distance and height of neighboring nodes, the model produced a very irregular route. The model would exhaust the nodes in the neighborhood before leaving that immediate region for any new points (Figure 7.2).

With the exposure value of a node added to the decision logic, this second level of information allowed the model to produce a node linkage which resembled a route (Figure 7.3). The third level provided data on radar location and range with which the model was able to produce a route that approximates the route an individual analyst would

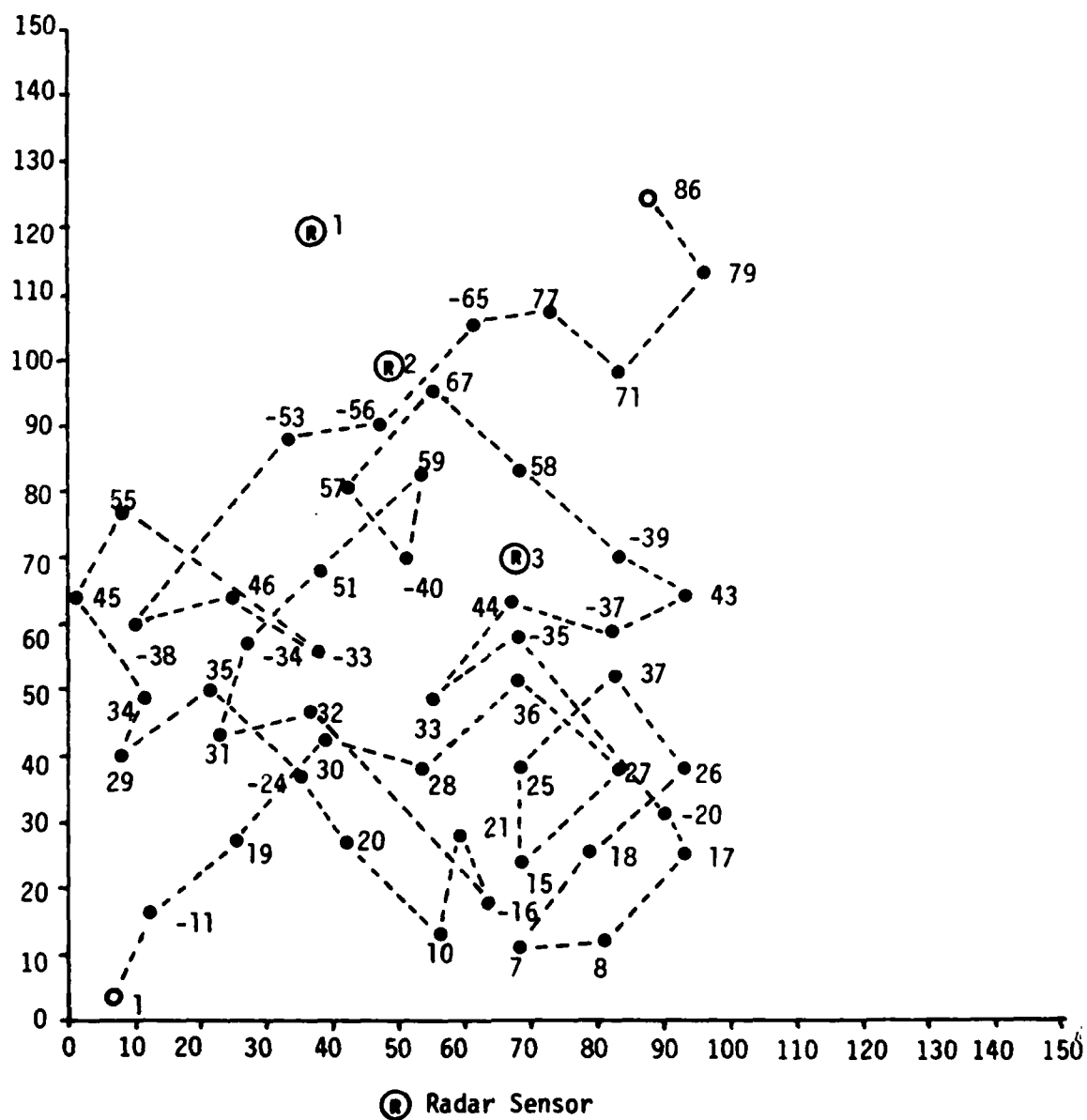


Figure 7.2. Minimal Information Route.

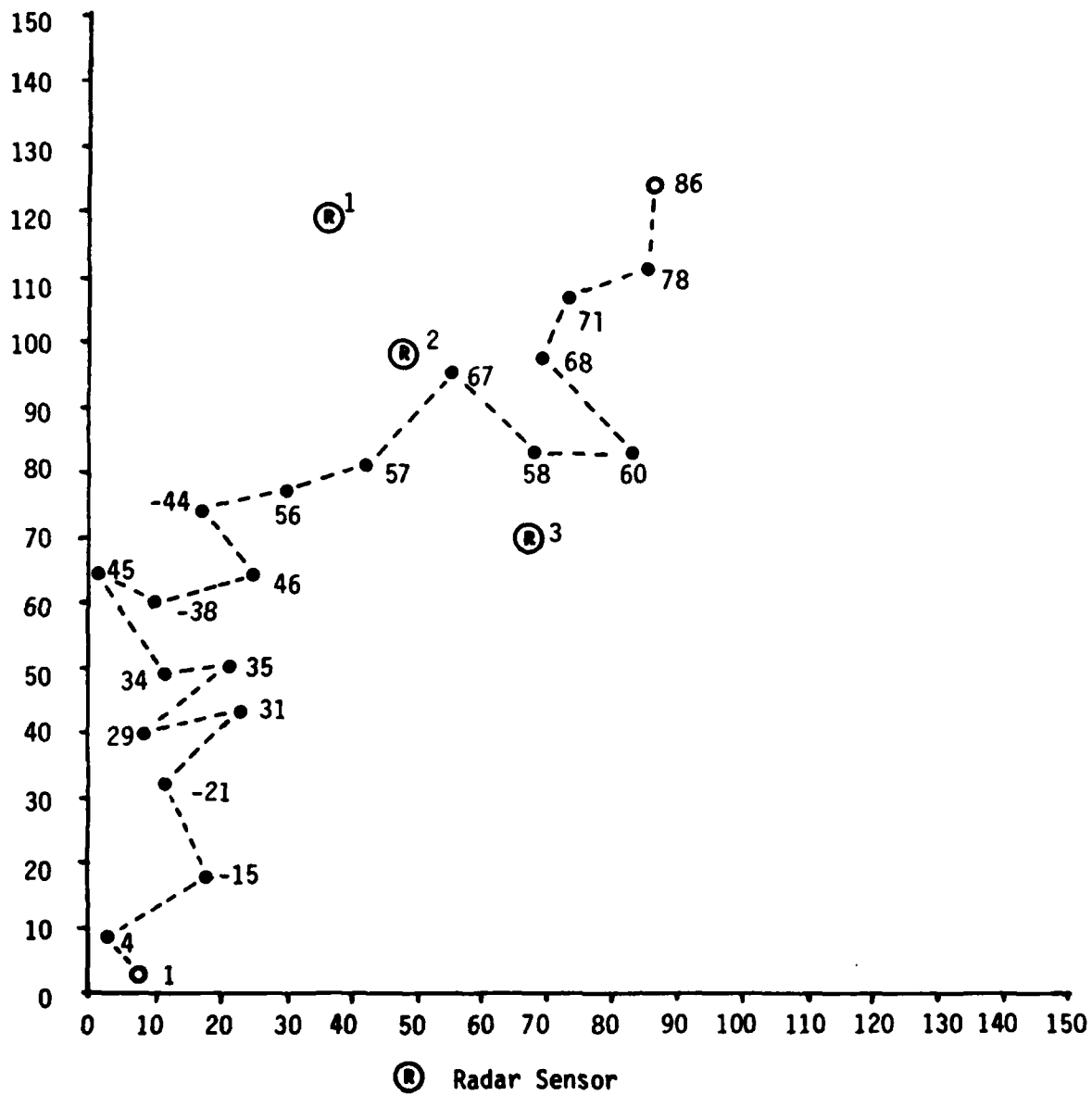


Figure 7.3. Exposure Value Route.

select (Figure 7.4). In Figure 7.4 the radars are deployed in the northern sector and the route avoids them by a southerly route.

When the destination is within 1 km of the current position the final terminal weighting forces the choice of the next position to be the destination or an intermediate node. Normal attacking procedures have some distance from target at which the attack is committed and one proceeds directly towards the target. With high speed aircraft (250 m/sec) this attack point is 3 to 6 km away depending on the type of ordnance being used. Stand-off munitions exist that allow the attacking aircraft to be 20 or more km away when releasing their ordnance, if the target is heavily defended.

The results of the model are a series of linked points which comprise a route. A comparison of Figure 7.4 with Figure 7.1 indicates that the preferred route C is approached with the radar avoidance weighting. The degree of match between the model route and the manual route give a visual indication of acceptability.

7.4 Model Evaluation

The exposure value of each route node point was used as a basis of comparison. Since the routes are not of equal length, the exposure of the node links were used to establish the exposure value of a route. The calculation of route exposure is given below:

$$EVR = \sum_{i=1}^{n-1} EV(N_{i+1}) \left[\frac{d_{i+1}}{D} \right]$$

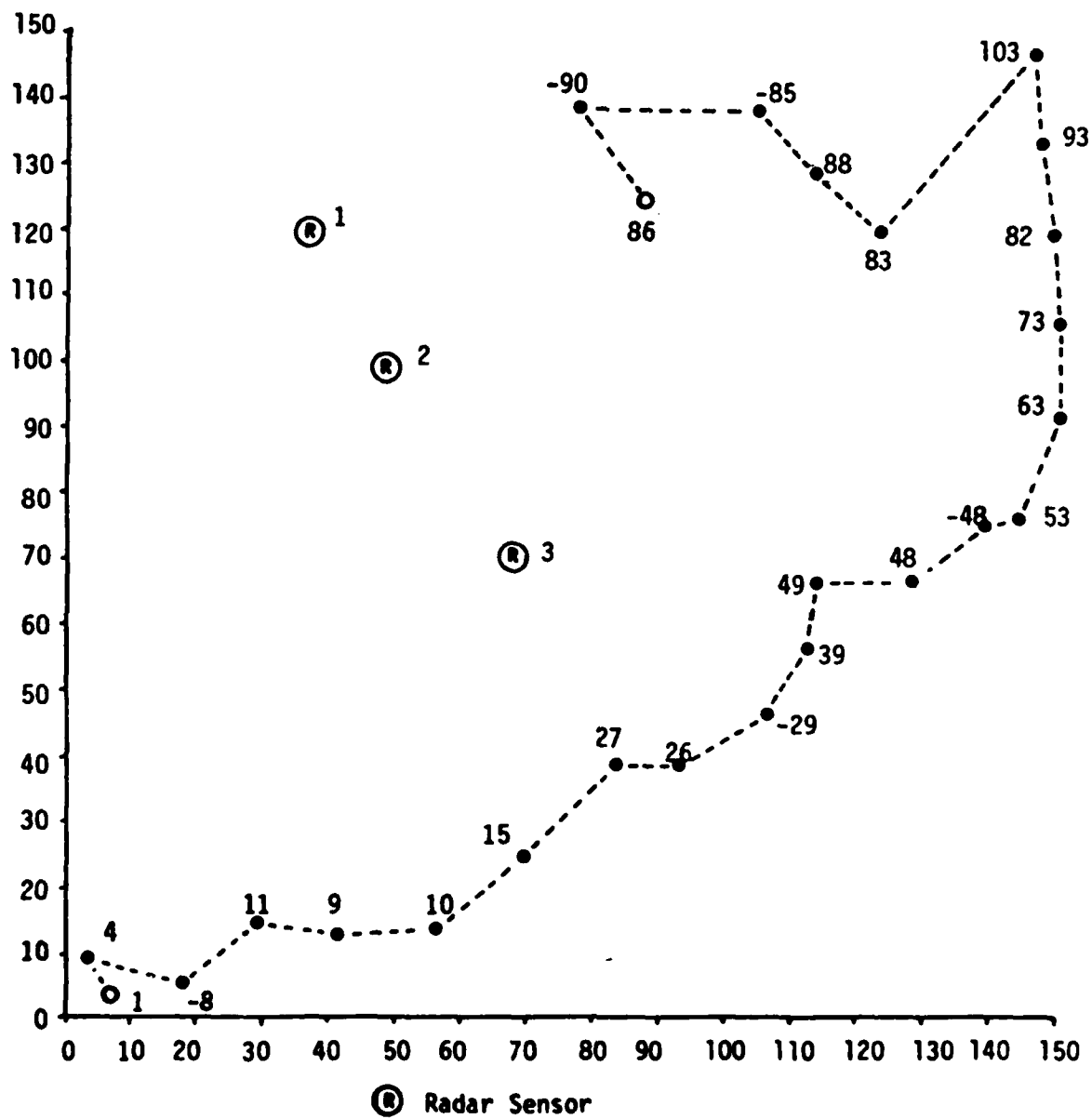


Figure 7.4. Complete Information Route.

$$\text{where } D = \sum_{i=1}^{n-1} d_{i+1},$$

D = The total length of the route,

$EV(N_{i+1})$ = The exposure value of route node $i+1$,

d_{i+1} = The distance from node i to node $i+1$,

EVR = The exposure value of the route.

Utilizing this relation the model routes can be compared with the manually chosen routes. The scenario for the manual selection and the model is Case 1. In Table 7.1 the route exposure values are given for the three manual routes and the model route. The preferred route C and the model route achieved an exposure value of 0.844 and 0.888 respectively.

The other routes that were developed by the model indicate that the deployment of the sensors within the terrain have a definite effect on the selection process. Rough terrain with sensors deployed to cover the low elevation corridors is the most difficult case for the model to evaluate and select a minimum exposure, minimum elevation route for penetrating the air defenses.

Table 7.1 Route Exposure Values

Route	EVR
A	1.582
B	1.325
C	0.844
Model	0.888

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

This research has addressed an area of air defense modeling which is normally analyzed visually with topographic maps and coverage diagrams before any tactical gaming is performed. A significant problem in analyzing terrain from a topographic map is perceiving the 3-dimensional aspects of terrain features. The degree of visibility a manually developed route will have can only, at best, be estimated. Any route selected is based on the particular individual's ability to be a good tactician. Using the subjective route for air defense modeling adds an unknown to the war gaming results.

The model that has been presented overcomes the shortcomings cited above and provides a minimum-exposure, minimum-elevation route. The developed route then serves as a baseline from which other flight paths can be evaluated. The model provides the visibility or exposure of all the high and low elevation nodes within the area. These values can be used as a reference for evaluating the visibility of specific areas of the terrain in addition to route identification.

Terrain roughness has a marked effect in the developed route. By placing the radar sensors at key positions to cover approach corridors, the model develops long routes in searching for a minimum exposure route. The long routes indicate the problem of traversing an area undetected by modern air defenses. The addition of more sensors

increases the penalty associated with travel through an area and also increases the route length. In the 35 by 35 km case the penalty value increased from 12783 for the three radar case to 95154 for the ten radar case. The route nodes also varied from 181 to 466 in the initial routes.

8.2 Recommendations for Further Research

In testing this model it became very obvious that minor changes in weighting of a single node point would result in an entirely different route. Further research is needed into the sensitivity of the weighting scheme utilized in this model.

The decision logic that is used in this model is by no means the only one that should be used. There needs to be the ability to enter check points through which the route must pass on its way to the destination. Along this same line of reasoning, the model could be modified to evaluate a proposed route rather than find the route.

The idea of limiting the next node selection to a neighborhood about the current position could be expanded to other problems besides air defense aircraft routes. The routing of oil and gas pipelines could be analyzed using the model. The radar sites could be a town or built up areas to be avoided. The weighting of the height penalty could be increased to favor level terrain.

Lastly, the author hopes that this research might serve as a start for further effort into the general problem of routing.

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APPENDICES

APPENDIX A

ROUTING PROBLEMS

Within this appendix are the data tables for the additional problem cases discussed in Chapter 6. Each set of tables is preceded by a page identifying the case. The tables for exposure values in these cases were not included for the sake of brevity.

Case 2 - Area 1, Route 2, Sensor set 1.

Table A.1. Case 2 - Node Linkage for Route

FROM	EASTING	NORTHING	TO	PENALTY	EASTING	NORTHING
31	770	10150	30	26	1610	10010
30	1610	10010	28	74	560	9800
28	560	9800	35	2	1470	10500
35	1470	10500	34	184	770	10430
34	770	10430	45	1	70	11480
45	70	11480	-38	154	700	11200
-38	700	11200	-42	260	560	12040
-42	560	12040	-52	231	560	13090
-52	560	13090	-44	97	1190	12180
-44	1190	12180	46	188	1750	11480
46	1750	11480	-33	214	2660	10920
-33	2660	10920	32	354	2590	10290
32	2590	10290	-22	452	3290	9240
-22	3290	9240	29	145	2730	9940
29	2730	9940	24	232	3710	9660
24	3710	9660	25	243	4760	9660
25	4760	9660	33	228	3650	10430
33	3650	10430	36	295	4760	10570
36	4760	10570	37	240	5810	10640
37	5810	10640	38	198	6510	10780
38	6510	10780	43	298	6580	11410
43	6580	11410	52	278	6580	12320
52	6580	12320	61	265	7560	13230
61	7560	13230	-46	252	8540	12250
-46	8540	12250	54	87	9380	12320
54	9380	12320	53	56	10080	12320
53	10080	12320	63	71	10500	13370
63	10500	13370	73	27	10500	14350
73	10500	14350	82	47	10430	15330
82	10430	15330	92	96	10290	16240
92	10290	16240	96	285	9450	16450

Table A.2. Case 2 - Node Linkage

NODE NO.	31	TOTAL LINKS	7						
X,Y,Z COORDINATE	11,	45,	280						
LINKED TO	34	28	35	30	-21	-23	-38		
EXPOSURE	100	53	34	26	161	241	160		
WEIGHTED	101	168	70	26	324	242	161		
NODE NO.	30	TOTAL LINKS	9						
X,Y,Z COORDINATE	23,	43,	280						
LINKED TO	35	34	32	28	-23	-24	-34	-21	-33
EXPOSURE	100	51	118	36	156	280	343	186	308
WEIGHTED	101	104	238	74	714	281	688	374	618
NODE NO.	28	TOTAL LINKS	4						
X,Y,Z COORDINATE	8,	40,	280						
LINKED TO	34	35	-21	-23					
EXPOSURE	88	0	258	295					
WEIGHTED	178	2	516	296					
NODE NO.	35	TOTAL LINKS	6						
X,Y,Z COORDINATE	21,	50,	280						
LINKED TO	34	46	-34	-38	-23	-24			
EXPOSURE	91	258	373	203	274	213			
WEIGHTED	184	518	742	408	550	214			
NODE NO.	34	TOTAL LINKS	3						
X,Y,Z COORDINATE	11,	49,	280						
LINKED TO	45	-38	-23						
EXPOSURE	3	254	180						
WEIGHTED	1	255	181						
NODE NO.	45	TOTAL LINKS	3						
X,Y,Z COORDINATE	1,	64,	300						
LINKED TO	55	-36	-42						
EXPOSURE	224	163	211						
WEIGHTED	458	164	424						
NODE NO.	-38	TOTAL LINKS	3						
X,Y,Z COORDINATE	10,	50,	310						
LINKED TO	46	-42	-44						
EXPOSURE	151	259	165						
WEIGHTED	304	260	332						
NODE NO.	-42	TOTAL LINKS	3						
X,Y,Z COORDINATE	9,	72,	330						
LINKED TO	55	-44	-52						
EXPOSURE	279	126	230						
WEIGHTED	280	254	231						
NODE NO.	-52	TOTAL LINKS	5						
X,Y,Z COORDINATE	8,	57,	350						
LINKED TO	55	70	-54	-44	-59				
EXPOSURE	270	313	339	56	246				
WEIGHTED	542	314	440	97	494				
NODE NO.	-44	TOTAL LINKS	5						
X,Y,Z COORDINATE	17,	74,	330						
LINKED TO	55	46	56	-43	-54				
EXPOSURE	339	167	208	251	242				
WEIGHTED	620	168	418	504	486				
NODE NO.	46	TOTAL LINKS	5						
X,Y,Z COORDINATE	25,	64,	300						
LINKED TO	51	56	-34	-43	-33				
EXPOSURE	250	266	306	360	213				
WEIGHTED	502	534	614	722	214				
NODE NO.	-33	TOTAL LINKS	4						
X,Y,Z COORDINATE	39,	56,	300						
LINKED TO	32	51	29	-36	-34	-40			
EXPOSURE	176	395	177	404	381	335			
WEIGHTED	354	792	356	810	764	3360			

Table A.2. (cont'd.)

NODE NO. 32 TOTAL LINKS 5
 X,Y,Z COORDINATE 37, 47, 280
 LINKED TO 29 -24 -34 -36 -22
 EXPOSURE 227 291 332 332 225
 WEIGHTED 456 584 666 666 452

NODE NO. -22 TOTAL LINKS 6
 X,Y,Z COORDINATE 47, 32, 290
 LINKED TO 18 24 20 29 -24 -14
 EXPOSURE 319 268 190 144 242 247
 WEIGHTED 632 534 191 145 488 496

NODE NO. 29 TOTAL LINKS 5
 X,Y,Z COORDINATE 39, 42, 280
 LINKED TO 24 18 19 -24 -34
 EXPOSURE 231 252 253 329 310
 WEIGHTED 232 506 508 660 311

NODE NO. 24 TOTAL LINKS 6
 X,Y,Z COORDINATE 53, 36, 280
 LINKED TO 22 20 25 18 36 -34
 EXPOSURE 274 265 242 307 219 416
 WEIGHTED 487 532 243 616 2100 1234

NODE NO. 25 TOTAL LINKS 8
 X,Y,Z COORDINATE 68, 32, 280
 LINKED TO 36 20 13 27 17 33 37 -24
 EXPOSURE 309 269 258 270 249 227 275 369
 WEIGHTED 3100 540 518 271 500 228 276 740

NODE NO. 33 TOTAL LINKS 4
 X,Y,Z COORDINATE 55, 49, 280
 LINKED TO 36 44 -36 -35
 EXPOSURE 254 278 418 303
 WEIGHTED 295 2740 419 3040

NODE NO. 36 TOTAL LINKS 6
 X,Y,Z COORDINATE 68, 51, 280
 LINKED TO 44 37 47 27 -35 -37
 EXPOSURE 197 219 337 176 414 331
 WEIGHTED 3880 240 3380 354 4150 332

NODE NO. 37 TOTAL LINKS 7
 X,Y,Z COORDINATE 83, 52, 280
 LINKED TO 38 42 27 43 26 -37 -35
 EXPOSURE 197 363 234 364 166 400 320
 WEIGHTED 198 364 418 305 334 4010 3210

NODE NO. 38 TOTAL LINKS 5
 X,Y,Z COORDINATE 53, 54, 280
 LINKED TO 43 42 -37 -29 -28
 EXPOSURE 297 250 258 245 258
 WEIGHTED 298 2510 2590 492 518

NODE NO. 43 TOTAL LINKS 5
 X,Y,Z COORDINATE 94, 62, 290
 LINKED TO 42 52 -37 -39 -47
 EXPOSURE 311 277 262 290 286
 WEIGHTED 3128 278 526 2910 287

NODE NO. 52 TOTAL LINKS 8
 X,Y,Z COORDINATE 54, 76, 300
 LINKED TO 60 62 42 61 -45 -47 -50 -39
 EXPOSURE 291 277 231 264 354 335 342 288
 WEIGHTED 584 278 464 265 710 336 343 2890

NODE NO. 61 TOTAL LINKS 9
 X,Y,Z COORDINATE 109, 89, 336
 LINKED TO 66 72 -51 -50 -60 -62 -47 -45 -46
 EXPOSURE 339 227 346 341 313 313 245 287 125
 WEIGHTED 340 456 694 684 316 314 572 576 252

Table A.2. (cont'd.)

NODE NO.	46	TOTAL LINKS	6			
X,Y,Z COORDINATE	122,	75,	330			
LINKED TO	48	54	48	-45	-51	-55
EXPOSURE	146	86	234	310	128	237
WEIGHTED	294	87	470	662	129	238

NODE NO.	54	TOTAL LINKS	6			
X,Y,Z COORDINATE	134,	76,	310			
LINKED TO	53	48	50	-44	-55	-57
EXPOSURE	55	103	90	110	234	224
WEIGHTED	56	208	182	222	235	225

NODE NO.	53	TOTAL LINKS	5			
X,Y,Z COORDINATE	144,	76,	300			
LINKED TO	50	63	-48	-57	-55	
EXPOSURE	128	70	110	246	215	
WEIGHTED	258	71	222	247	216	

NODE NO.	63	TOTAL LINKS	5			
X,Y,Z COORDINATE	150,	51,	360			
LINKED TO	73	-57	-61	-55	-58	
EXPOSURE	26	259	283	176	235	
WEIGHTED	27	600	284	354	472	

NODE NO.	73	TOTAL LINKS	7			
X,Y,Z COORDINATE	150,	105,	360			
LINKED TO	82	-69	-61	-67	-58	-57
EXPOSURE	56	322	312	266	270	241
WEIGHTED	57	323	626	534	542	484

NODE NO.	82	TOTAL LINKS	5			
X,Y,Z COORDINATE	147,	119,	340			
LINKED TO	92	-77	-69	-75	-67	
EXPOSURE	95	200	288	161	221	
WEIGHTED	96	205	576	162	444	

NODE NO.	92	TOTAL LINKS	5			
X,Y,Z COORDINATE	147,	132,	330			
LINKED TO	96	103	-77	-92	-76	
EXPOSURE	284	61	245	146	155	
WEIGHTED	285	1260	750	1470	4620	

Case 3 - Area 1, Route 1, Sensor Set 2.

Table A

FROM	EASTING	NORTH				
1	690	11110			690	11110
-11	690	11110			690	11110
19	1730	11110			1730	11110
38	2730	11110			2730	11110
28	3730	11110			3730	11110
36	4730	11110			4730	11110
27	5810	11110			5810	11110
26	6910	11110			6910	11110
18	5530	11110			5530	11110
25	4730	11110			4730	11110
13	3890	11110			3890	11110
-35	4730	11110			4730	11110
47	3920	11110			3920	11110
44	4690	11110			4690	11110
43	4580	11110			4580	11110
-47	7280	11110			7280	11110
52	6580	11110			6580	11110
60	5810	11110			5810	11110
-41	4730	11110			4730	11110
-37	5740	11110			5740	11110
38	6510	11110			6510	11110
42	5880	11110			5880	11110
49	7910	11110			7910	11110
48	8940	11110			8940	11110
50	10010	11110			10010	11110
54	9380	11110			9380	11110
-46	8540	11110			8540	11110
-55	9450	11110			9450	11110
53	10080	11110			10080	11110
63	10500	11110			10500	11110
73	10500	11110			10500	11110
82	10430	11110			10430	11110
93	10290	11110			10290	11110
103	10220	11110			10220	11110
-92	9800	11110			9800	11110
-93	8050	11110			8050	11110
-85	7280	11110			7280	11110
92	6370	11110			6370	11110

Table A.4. Case 3 - Node Linkage

NODE NO.	1	TOTAL LINKS	4						
X,Y,Z COORDINATE	7,	3,	270						
LINKED TO	4	-6	-8	-11					
EXPOSURE	85	223	173	67					
WEIGHTED	86	224	174	68					

NODE NO.	-11	TOTAL LINKS	6						
X,Y,Z COORDINATE	12,	16,	330						
LINKED TO	14	4	19	-15	-6	-8			
EXPOSURE	95	52	40	174	170	171			
WEIGHTED	96	106	41	175	342	344			

NODE NO.	19	TOTAL LINKS	7						
X,Y,Z COORDINATE	25,	27,	300						
LINKED TO	11	30	-23	-15	-13	-24	-21		
EXPOSURE	154	53	180	221	173	123	103		
WEIGHTED	310	54	181	444	342	124	208		

NODE NO.	30	TOTAL LINKS	7						
X,Y,Z COORDINATE	35,	42,	280						
LINKED TO	32	28	20	-24	-22	-33	-34		
EXPOSURE	154	91	123	189	146	150	179		
WEIGHTED	155	92	248	380	294	151	180		

NODE NO.	22	TOTAL LINKS	6						
X,Y,Z COORDINATE	53,	32,	280						
LINKED TO	33	21	25	20	36	-22			
EXPOSURE	140	126	105	176	70	243			
WEIGHTED	141	254	106	354	71	468			

NODE NO.	36	TOTAL LINKS	8						
X,Y,Z COORDINATE	66,	51,	250						
LINKED TO	44	25	35	37	47	27	-35	-37	
EXPOSURE	232	120	120	115	173	65	265	201	
WEIGHTED	233	242	242	116	348	132	266	202	

NODE NO.	37	TOTAL LINKS	8						
X,Y,Z COORDINATE	83,	52,	280						
LINKED TO	36	42	27	43	26	25	-37	-35	
EXPOSURE	76	242	114	127	24	62	265	194	
WEIGHTED	77	486	233	128	56	126	270	195	

NODE NO.	26	TOTAL LINKS	7						
X,Y,Z COORDINATE	93,	35,	280						
LINKED TO	27	17	18	-20	-28	-29	-18		
EXPOSURE	143	128	57	181	210	115	122		
WEIGHTED	144	258	116	364	211	116	246		

NODE NO.	18	TOTAL LINKS	9						
X,Y,Z COORDINATE	75,	26,	280						
LINKED TO	15	27	17	8	25	7	-20	-12	-16
EXPOSURE	154	136	160	150	90	94	187	192	115
WEIGHTED	310	137	161	302	91	190	186	386	234

NODE NO.	25	TOTAL LINKS	5						
X,Y,Z COORDINATE	66,	35,	280						
LINKED TO	21	15	27	33	-12				
EXPOSURE	154	148	149	126	474				
WEIGHTED	310	298	150	127	950				

NODE NO.	33	TOTAL LINKS	3						
X,Y,Z COORDINATE	55,	49,	280						
LINKED TO	44	-36	-35						
EXPOSURE	75	255	106						
WEIGHTED	152	256	107						

NODE NO.	-35	TOTAL LINKS	5						
X,Y,Z COORDINATE	68,	59,	290						
LINKED TO	44	47	-41	-37	-35				
EXPOSURE	175	106	215	110	176				
WEIGHTED	176	107	216	111	354				

Table A.4. (cont'd.)

NODE NO. 47 TOTAL LINKS 4											
X,Y,Z COORDINATE	56.	65.	290								
LINKED TO	44	-40	-36	-41							
EXPOSURE	110	260	209	170							
WEIGHTED	111	261	420	342							
NODE NO. 44 TOTAL LINKS 21											
X,Y,Z COORDINATE	57.	63.	290								
LINKED TO	42	58	59	60	43	38	51	27	52	57	
LINKED TO	32	62	65	-41	-37	-40	-35	-36	-49	-33	
LINKED TO	-56										
EXPOSURE	183	207	237	197	68	34	195	93	90	202	
EXPOSURE	67	168	216	243	185	202	215	190	220	149	
EXPOSURE	233										
WEIGHTED	184	208	2380	396	65	70	392	188	910	203	
WEIGHTED	136	338	2170	244	186	203	2190	382	442	300	
WEIGHTED	2340										
NODE NO. 43 TOTAL LINKS 6											
X,Y,Z COORDINATE	94.	63.	290								
LINKED TO	38	42	52	-37	-39	-47					
EXPOSURE	100	186	79	143	163	98					
WEIGHTED	202	187	600	288	164	99					
NODE NO. 47 TOTAL LINKS 8											
X,Y,Z COORDINATE	104.	75.	330								
LINKED TO	52	49	61	62	-50	-45	-51	-49			
EXPOSURE	62	42	172	98	268	149	220	139			
WEIGHTED	63	86	356	990	2690	300	221	1400			
NODE NO. 52 TOTAL LINKS 7											
X,Y,Z COORDINATE	94.	76.	300								
LINKED TO	60	62	42	61	-45	-50	-55				
EXPOSURE	156	162	101	169	232	243	153				
WEIGHTED	157	1630	204	340	2330	244	302				
NODE NO. 60 TOTAL LINKS 6											
X,Y,Z COORDINATE	63.	83.	300								
LINKED TO	62	58	58	-49	-39	-41					
EXPOSURE	172	122	151	284	141	84					
WEIGHTED	1730	246	304	2650	284	170					
NODE NO. 41 TOTAL LINKS 4											
X,Y,Z COORDINATE	68.	71.	300								
LINKED TO	58	59	-35	-37							
EXPOSURE	173	219	234	80							
WEIGHTED	174	2200	235	180							
NODE NO. 47 TOTAL LINKS 3											
X,Y,Z COORDINATE	82.	55.	290								
LINKED TO	42	38	-35								
EXPOSURE	229	0	194								
WEIGHTED	230	2	390								
NODE NO. 38 TOTAL LINKS 3											
X,Y,Z COORDINATE	93.	54.	290								
LINKED TO	42	-25	-28								
EXPOSURE	151	48	167								
WEIGHTED	162	158	336								
NODE NO. 42 TOTAL LINKS 13											
X,Y,Z COORDINATE	84.	63.	290								
LINKED TO	27	58	62	39	45	61	24	-39	-49	-29	
LINKED TO	-50	-28	-45								
EXPOSURE	113	158	169	65	64	185	32	218	202	104	
EXPOSURE	227	189	123								
WEIGHTED	222	318	340	132	65	372	66	438	2090	210	
WEIGHTED	2283	360	124								
NODE NO. 45 TOTAL LINKS 6											
X,Y,Z COORDINATE	113.	66.	300								
LINKED TO	39	48	41	-45	-46	-50					
EXPOSURE	85	15	31	197	120	188					
WEIGHTED	172	32	64	198	121	1890					
NODE NO. 48 TOTAL LINKS 8											
X,Y,Z COORDINATE	128.	66.	300								
LINKED TO	41	54	50	-46	-32	-48	-45	-31			
EXPOSURE	124	81	24	137	126	57	95	73			
WEIGHTED	250	82	80	276	254	58	203	148			

Table A.4. (cont'd)

NODE NO.	50	TOTAL LINKS	6				
X,Y,Z COORDINATE	143,	64,	300				
LINKED TO	53	40	54	-48	-31	-32	
EXPOSURE	100	90	98	132	135	96	
WEIGHTED	101	182	99	133	272	154	
NODE NO.	54	TOTAL LINKS	5				
X,Y,Z COORDINATE	134,	76,	310				
LINKED TO	53	-48	-46	-55	-57		
EXPOSURE	55	110	69	169	168		
WEIGHTED	112	222	70	170	165		
NODE NO.	-46	TOTAL LINKS	4				
X,Y,Z COORDINATE	122,	75,	330				
LINKED TO	61	-45	-51	-55			
EXPOSURE	91	124	219	171			
WEIGHTED	920	250	2200	172			
NODE NO.	-55	TOTAL LINKS	8				
X,Y,Z COORDINATE	135,	70,	370				
LINKED TO	69	63	53	73	-57	-58	-61
EXPOSURE	183	102	32	59	258	272	166
WEIGHTED	1540	206	66	120	518	273	338
NODE NO.	53	TOTAL LINKS	3				
X,Y,Z COORDINATE	144,	76,	300				
LINKED TO	63	-48	-57				
EXPOSURE	61	100	186				
WEIGHTED	62	101	187				
NODE NO.	63	TOTAL LINKS	4				
X,Y,Z COORDINATE	150,	51,	360				
LINKED TO	73	-57	-61	-58			
EXPOSURE	26	242	157	170			
WEIGHTED	27	243	316	342			
NODE NO.	73	TOTAL LINKS	6				
X,Y,Z COORDINATE	150,	105,	360				
LINKED TO	82	-69	-51	-67	-58	-57	
EXPOSURE	35	348	181	262	171	151	
WEIGHTED	36	658	182	2630	172	152	
NODE NO.	82	TOTAL LINKS	5				
X,Y,Z COORDINATE	149,	119,	340				
LINKED TO	93	-77	-69	-76	-67		
EXPOSURE	64	211	314	144	242		
WEIGHTED	65	212	315	166	243		
NODE NO.	93	TOTAL LINKS	4				
X,Y,Z COORDINATE	147,	132,	330				
LINKED TO	103	-77	-92	-76			
EXPOSURE	31	280	150	182			
WEIGHTED	64	562	161	1840			
NODE NO.	103	TOTAL LINKS	6				
X,Y,Z COORDINATE	145,	146,	320				
LINKED TO	90	63	-92	-87	-77	-76	
EXPOSURE	115	55	176	246	224	215	
WEIGHTED	1160	560	177	494	225	2160	
NODE NO.	-92	TOTAL LINKS	7				
X,Y,Z COORDINATE	140,	143,	330				
LINKED TO	90	63	88	-87	-77	-76	-93
EXPOSURE	143	100	164	295	250	238	179
WEIGHTED	1440	1010	1650	592	251	2390	180
NODE NO.	-93	TOTAL LINKS	4				
X,Y,Z COORDINATE	115,	144,	330				
LINKED TO	90	-75	-87	-81			
EXPOSURE	125	253	324	162			
WEIGHTED	1260	254	650	326			
NODE NO.	-85	TOTAL LINKS	3				
X,Y,Z COORDINATE	104,	137,	330				
LINKED TO	88	92	-81				
EXPOSURE	296	156	358				
WEIGHTED	2970	157	3590				
NODE NO.	92	TOTAL LINKS	9				
X,Y,Z COORDINATE	91,	129,	300				
LINKED TO	91	86	99	80	-81	-78	-90
EXPOSURE	253	281	96	208	315	255	196
WEIGHTED	762	282	48500	62700	156000	25600	59700

Case 4 - Area 1, Route 2, Sensor Set 2.

Table A.5. Case 4 - Node Linkage for Route

FROM	EASTING	NORTHING	TO	PENALTY	EASTING	NORTHING
31	770	10150	35	164	1470	10500
35	1470	10500	-24	165	2450	9590
-24	2450	9590	-22	177	3290	9240
-22	3290	9240	32	145	2590	10290
32	2590	10290	30	220	1610	10010
30	1610	10010	28	230	560	9600
28	560	9800	34	185	770	10430
34	770	10430	45	34	70	11480
45	70	11480	55	205	560	12390
55	560	12390	-33	153	2660	10520
-33	2660	10920	51	337	2660	11760
51	2660	11760	57	198	2940	12670
57	2940	12670	67	192	3650	13650
67	3650	13650	76	334	3920	14420
76	3920	14420	-73	302	4550	15120
-73	4550	15120	-78	261	5390	15890
-78	5390	15890	-90	281	5390	16660
-90	5390	16660	89	320	6370	16030
89	6370	16030	99	270	5810	17010
99	5810	17010	91	604	6020	16030
91	6020	16030	94	566	5250	16450
94	5250	16450	104	128	4760	17290
104	4760	17290	102	2	3710	17220
102	3710	17220	100	2	2660	17080
100	2660	17080	93	14	1610	16450
93	1610	16450	84	2	1120	15400
84	1120	15400	85	101	1120	15540
85	1120	15540	97	32	580	16590
97	980	16590	86	202	770	15890
86	770	15890	98	1	1750	16870
98	1750	16870	81	46	490	15190
81	490	15190	95	29	2240	16450
95	2240	16450	-66	177	3080	16590
-66	3080	16590	-98	296	3430	16590
-98	3430	16590	-89	167	4480	16660
-89	4480	16660	87	340	3990	15960
87	3990	15960	-65	290	4270	14350
-65	4270	14350	-56	408	3290	13300
-56	3290	13300	-63	274	3290	14280
-63	3290	14280	-74	274	3430	15120
-74	3430	15120	-82	309	3360	16030
-82	3360	16030	-59	462	1540	13930
-59	1540	13930	-71	284	1750	14910
-71	1750	14910	-53	240	2310	13160
-53	2310	13160	-43	302	2240	12180
-43	2240	12180	46	374	1750	11480
46	1750	11480	56	200	2100	12390
56	2100	12390	64	234	2100	13370
64	2100	13370	75	215	3150	14420
75	3150	14420	-72	490	2450	15050
-72	2450	15050	65	217	3080	13510
65	3080	13510	-64	494	2240	14280
-64	2240	14280	-83	274	2870	16100
-83	2870	16100	101	98	6720	17150
101	6720	17150	-93	307	8050	17080
-93	8050	17080	-87	325	8890	16590
-87	8890	16590	96	340	9450	16450

Table A.6. Case 4 - Node Linkage

NODE NO. 31 TOTAL LINKS 7										
X,Y,Z COORDINATE 11, 45, 280										
LINKED TO	34	28	35	30	-21	-23	-36			
EXPOSURE	201	158	81	119	139	180	203			
WEIGHTED	202	318	164	240	280	181	204			
NODE NO. 35 TOTAL LINKS 8										
X,Y,Z COORDINATE 21, 50, 280										
LINKED TO	30	34	46	28	-34	-38	-23	-24		
EXPOSURE	193	178	237	98	282	238	207	164		
WEIGHTED	388	358	238	199	283	478	416	165		
NODE NO. -24 TOTAL LINKS 7										
X,Y,Z COORDINATE 35, 37, 290										
LINKED TO	29	32	18	30	19	-22	-23			
EXPOSURE	243	195	178	103	201	176	203			
WEIGHTED	488	196	356	208	404	177	406			
NODE NO. -22 TOTAL LINKS 6										
X,Y,Z COORDINATE 47, 32, 290										
LINKED TO	18	24	20	29	32	-14				
EXPOSURE	253	211	171	190	144	235				
WEIGHTED	508	424	172	191	145	472				
NODE NO. 32 TOTAL LINKS 5										
X,Y,Z COORDINATE 37, 47, 280										
LINKED TO	25	30	-33	-34	-36					
EXPOSURE	243	109	314	249	266					
WEIGHTED	488	220	315	500	534					
NODE NO. 30 TOTAL LINKS 6										
X,Y,Z COORDINATE 23, 43, 280										
LINKED TO	34	28	-23	-34	-21	-33				
EXPOSURE	157	114	303	275	167	248				
WEIGHTED	316	230	606	276	336	498				
NODE NO. 28 TOTAL LINKS 3										
X,Y,Z COORDINATE 8, 40, 280										
LINKED TO	34	-21	-23							
EXPOSURE	184	236	203							
WEIGHTED	185	474	204							
NODE NO. 34 TOTAL LINKS 3										
X,Y,Z COORDINATE 11, 49, 280										
LINKED TO	45	-18	-23							
EXPOSURE	33	297	119							
WEIGHTED	34	298	120							
NODE NO. 45 TOTAL LINKS 3										
X,Y,Z COORDINATE 1, 64, 300										
LINKED TO	55	-38	-42							
EXPOSURE	204	256	255							
WEIGHTED	205	267	256							
NODE NO. 55 TOTAL LINKS 16										
X,Y,Z COORDINATE 8, 77, 340										
LINKED TO	70	46	56	64	51	-42	-44	-52	-54	-38
LINKED TO	-43	-59	-53	-34	-64	-33				
EXPOSURE	254	192	213	240	176	265	268	290	291	187
EXPOSURE	209	263	242	163	247	152				
WEIGHTED	255	183	428	241	354	532	538	291	292	376
WEIGHTED	420	264	486	164	248	153				
NODE NO. -33 TOTAL LINKS 6										
X,Y,Z COORDINATE 78, 56, 300										
LINKED TO	51	29	46	-36	-34	-40				
EXPOSURE	336	201	274	366	323	277				
WEIGHTED	337	404	550	367	648	556				
NODE NO. 51 TOTAL LINKS 7										
X,Y,Z COORDINATE 78, 49, 300										
LINKED TO	56	46	57	-43	-40	-36	-34			
EXPOSURE	288	162	197	341	216	201	134			
WEIGHTED	578	326	198	684	434	202	270			

Table A.6. (cont'd.)

NODE NO. 57 TOTAL LINKS 9
 X,Y,Z COORDINATE 42, 81, 300
 LINKED TO 59 65 56 64 67 -56 -53 -43 -40
 EXPOSURE 279 284 253 284 191 310 328 261 237
 WEIGHTED 568 285 508 570 192 311 676 524 238

NODE NO. 67 TOTAL LINKS 9
 X,Y,Z COORDINATE 55, 95, 300
 LINKED TO 76 65 59 68 75 58 -56 -65 -63
 EXPOSURE 333 264 256 257 300 213 310 334 339
 WEIGHTED 334 570 514 516 602 428 622 335 680

NODE NO. 76 TOTAL LINKS 7
 X,Y,Z COORDINATE 56, 106, 320
 LINKED TO 75 68 65 -65 -63 -74 -73
 EXPOSURE 296 229 197 345 314 310 301
 WEIGHTED 594 2250 395 692 630 622 302

NODE NO. -73 TOTAL LINKS 6
 X,Y,Z COORDINATE 65, 116, 330
 LINKED TO 77 87 -65 -75 -80 -78
 EXPOSURE 306 307 361 362 369 260
 WEIGHTED 3070 616 724 726 370 261

NODE NO. -78 TOTAL LINKS 7
 X,Y,Z COORDINATE 77, 127, 320
 LINKED TO 94 91 89 -75 -80 -90 -89
 EXPOSURE 314 290 192 363 355 280 262
 WEIGHTED 630 582 386 728 720 281 526

NODE NO. -50 TOTAL LINKS 4
 X,Y,Z COORDINATE 77, 138, 310
 LINKED TO 91 89 -89 -80
 EXPOSURE 301 159 355 343
 WEIGHTED 604 320 712 688

NODE NO. 89 TOTAL LINKS 6
 X,Y,Z COORDINATE 51, 129, 300
 LINKED TO 91 99 80 -81 -85 -75
 EXPOSURE 301 134 209 363 288 293
 WEIGHTED 604 270 2100 3640 289 588

NODE NO. 99 TOTAL LINKS 2
 X,Y,Z COORDINATE 93, 143, 300
 LINKED TO 91 -85
 EXPOSURE 301 454
 WEIGHTED 604 4950

NODE NO. 91 TOTAL LINKS 2
 X,Y,Z COORDINATE 86, 129, 300
 LINKED TO 94 -75
 EXPOSURE 282 298
 WEIGHTED 566 598

NODE NO. 94 TOTAL LINKS 3
 X,Y,Z COORDINATE 75, 135, 310
 LINKED TO 104 -80 -85
 EXPOSURE 63 379 335
 WEIGHTED 128 760 660

NODE NO. 104 TOTAL LINKS 2
 X,Y,Z COORDINATE 69, 147, 300
 LINKED TO 102 -89
 EXPOSURE 0 362
 WEIGHTED 2 726

NODE NO. 102 TOTAL LINKS 4
 X,Y,Z COORDINATE 53, 146, 300
 LINKED TO 100 -88 -86 -89
 EXPOSURE 0 345 195 268
 WEIGHTED 2 692 392 536

Table A.6. (cont'd.)

NODE NO. 100 TOTAL LINKS 7										
X,Y,Z COORDINATE 30, 144, 300										
LINKED TO	95	98	93	-86	-88	-83	-82			
EXPOSURE	101	53	6	230	283	284	253			
WEIGHTED	204	108	14	462	568	285	508			
NODE NO. 93 TOTAL LINKS 8										
X,Y,Z COORDINATE 23, 135, 300										
LINKED TO	98	95	97	86	85	84	-75	-94		
EXPOSURE	100	53	71	20	17	0	297	133		
WEIGHTED	101	188	144	42	36	2	298	268		
NODE NO. 84 TOTAL LINKS 7										
X,Y,Z COORDINATE 16, 120, 300										
LINKED TO	85	86	81	-71	-79	-68	-84			
EXPOSURE	100	58	52	233	216	186	177			
WEIGHTED	101	116	106	466	217	374	356			
NODE NO. 95 TOTAL LINKS 7										
X,Y,Z COORDINATE 16, 122, 300										
LINKED TO	86	81	97	-79	-71	-68	-84			
EXPOSURE	100	66	15	234	233	168	177			
WEIGHTED	202	134	32	235	466	148	356			
NODE NO. 97 TOTAL LINKS 3										
X,Y,Z COORDINATE 14, 137, 300										
LINKED TO	86	-84	-79							
EXPOSURE	100	227	166							
WEIGHTED	202	456	374							
NODE NO. 86 TOTAL LINKS 4										
X,Y,Z COORDINATE 11, 127, 300										
LINKED TO	81	98	-84	-71						
EXPOSURE	90	0	277	193						
WEIGHTED	182	1	556	388						
NODE NO. 98 TOTAL LINKS 11										
X,Y,Z COORDINATE 25, 141, 300										
LINKED TO	81	-75	-83	-84	-91	-88	-84	-82	-72	-71
EXPOSURE	22	286	240	175	230	247	224	268	242	225
WEIGHTED	46	287	562	352	462	496	450	522	243	226
NODE NO. 81 TOTAL LINKS 14										
X,Y,Z COORDINATE 7, 117, 300										
LINKED TO	70	55	64	-68	-84	-71	-79	-59	-91	-72
EXPOSURE	232	28	191	261	261	259	236	242	213	241
WEIGHTED	466	29	192	262	524	520	235	243	428	484
NODE NO. 95 TOTAL LINKS 15										
X,Y,Z COORDINATE 32, 135, 310										
LINKED TO	87	75	-75	-83	-86	-82	-88	-94	-72	-71
EXPOSURE	235	217	273	290	176	281	257	133	263	238
WEIGHTED	472	218	548	582	177	564	258	268	264	478
NODE NO. -86 TOTAL LINKS 4										
X,Y,Z COORDINATE 44, 127, 340										
LINKED TO	87	-88	-83	-82						
EXPOSURE	169	255	315	314						
WEIGHTED	340	256	632	630						
NODE NO. -44 TOTAL LINKS 4										
X,Y,Z COORDINATE 49, 137, 340										
LINKED TO	87	-82	-83	-89						
EXPOSURE	212	351	302	166						
WEIGHTED	426	704	606	167						
NODE NO. -59 TOTAL LINKS 2										
X,Y,Z COORDINATE 64, 136, 330										
LINKED TO	87	-80								
EXPOSURE	169	263								
WEIGHTED	340	568								

Table A.6. (cont'd.)

NODE NO.	87	TOTAL LINKS	14								
X,Y,Z COORDINATE	57	128	330								
LINKED TO	75	77	78	71	-82	-80	-74	-83	-75	-65	
EXPOSURE	276	257	247	234	353	338	330	319	303	285	
WEIGHTED	554	2580	496	2350	708	678	662	640	609	290	

NODE NO.	-65	TOTAL LINKS	5								
X,Y,Z COORDINATE	61	105	320								
LINKED TO	68	77	-63	-74	-56						
EXPOSURE	314	304	318	313	203						
WEIGHTED	3150	610	638	628	408						

NODE NO.	-56	TOTAL LINKS	5								
X,Y,Z COORDINATE	47	90	310								
LINKED TO	65	59	-63	-55	-64						
EXPOSURE	292	258	273	252	246						
WEIGHTED	586	518	274	506	494						

NODE NO.	-63	TOTAL LINKS	5								
X,Y,Z COORDINATE	47	104	330								
LINKED TO	75	65	-74	-64	-72						
EXPOSURE	318	209	273	255	244						
WEIGHTED	638	428	274	512	490						

NODE NO.	-74	TOTAL LINKS	4								
X,Y,Z COORDINATE	49	116	340								
LINKED TO	75	-62	-72	-83							
EXPOSURE	269	306	281	239							
WEIGHTED	540	309	564	480							

NODE NO.	-82	TOTAL LINKS	10								
X,Y,Z COORDINATE	48	129	350								
LINKED TO	75	77	-83	-80	-72	-79	-71	-64	-75	-59	
EXPOSURE	275	233	342	305	308	279	265	277	273	230	
WEIGHTED	560	2348	686	612	618	560	532	556	546	462	

NODE NO.	-89	TOTAL LINKS	8								
X,Y,Z COORDINATE	22	59	350								
LINKED TO	64	70	-54	-64	-71	-68	-53	-52			
EXPOSURE	246	262	327	343	283	244	193	283			
WEIGHTED	494	526	642	344	284	490	388	408			

NODE NO.	-71	TOTAL LINKS	15								
X,Y,Z COORDINATE	25	111	350								
LINKED TO	75	64	78	65	55	-72	-64	-79	-68	-83	
EXPOSURE	271	245	228	226	185	309	336	273	245	263	
WEIGHTED	544	246	458	454	386	620	614	274	452	264	

NODE NO.	-93	TOTAL LINKS	4								
X,Y,Z COORDINATE	33	85	330								
LINKED TO	64	56	65	-43							
EXPOSURE	343	174	192	150							
WEIGHTED	488	350	386	302							

NODE NO.	-43	TOTAL LINKS	4								
X,Y,Z COORDINATE	32	74	310								
LINKED TO	55	66	-44	-54							
EXPOSURE	267	186	217	222							
WEIGHTED	526	374	436	446							

NODE NO.	44	TOTAL LINKS	4								
X,Y,Z COORDINATE	25	64	300								
LINKED TO	56	-34	-44	-38							
EXPOSURE	199	234	253	138							
WEIGHTED	200	470	588	278							

NODE NO.	56	TOTAL LINKS	3								
X,Y,Z COORDINATE	30	77	310								
LINKED TO	64	-44	-54								
EXPOSURE	233	223	220								
WEIGHTED	234	448	442								

Table A.6. (cont'd.)

NODE NO. 64 TOTAL LINKS 4
 X,Y,Z COORDINATE 30, 91, 330
 LINKED TO 65 75 -54 -64
 EXPOSURE 260 218 322 345
 WEIGHTED 522 219 646 345

NODE NO. 75 TOTAL LINKS 3
 X,Y,Z COORDINATE 85, 106, 330
 LINKED TO 65 -64 -72
 EXPOSURE 273 318 244
 WEIGHTED 548 638 490

NODE NO. -72 TOTAL LINKS 8
 X,Y,Z COORDINATE 25, 115, 350
 LINKED TO 65 70 -64 -75 -83 -68 -54 -52
 EXPOSURE 228 229 345 311 324 245 248 205
 WEIGHTED 229 460 692 624 325 492 498 412

NODE NO. 65 TOTAL LINKS 2
 X,Y,Z COORDINATE 44, 91, 310
 LINKED TO 59 -64
 EXPOSURE 289 246
 WEIGHTED 580 454

NODE NO. -64 TOTAL LINKS 9
 X,Y,Z COORDINATE 37, 104, 350
 LINKED TO 70 59 -54 -68 -79 -83 -52 -44 -84
 EXPOSURE 250 244 286 257 274 273 227 196 177
 WEIGHTED 502 450 574 516 275 274 456 394 356

NODE NO. -83 TOTAL LINKS 28
 X,Y,Z COORDINATE 41, 130, 350
 LINKED TO 77 69 70 76 55 71 58 101 79 72
 LINKED TO 60 62 52 -79 -80 -94 -75 -84 -68 -51
 LINKED TO -54 -52 -80 -44 -41 -42 -49 -39
 EXPOSURE 273 266 216 269 232 271 248 97 204 201
 EXPOSURE 184 193 167 286 301 157 292 237 226 227
 EXPOSURE 232 204 206 184 226 158 188 167
 WEIGHTED 2740 2670 434 540 234 2720 498 98 2050 2020
 WEIGHTED 1850 1840 1680 574 604 316 588 476 454 456

NODE NO. 101 TOTAL LINKS 6
 X,Y,Z COORDINATE 56, 145, 300
 LINKED TO 88 90 83 -85 -81 -93 -75 -80
 EXPOSURE 306 271 259 346 376 306 222 286
 WEIGHTED 3070 2720 2600 694 3770 307 446 574

NODE NO. -93 TOTAL LINKS 4
 X,Y,Z COORDINATE 115, 144, 330
 LINKED TO 90 -85 -87 -81
 EXPOSURE 194 255 324 210
 WEIGHTED 1550 512 325 422

NODE NO. -87 TOTAL LINKS 6
 X,Y,Z COORDINATE 127, 137, 340
 LINKED TO 96 98 88 -92 -76 -77
 EXPOSURE 339 252 182 171 230 289
 WEIGHTED 340 126500 91500 17200 69300 21000

Case 5 - Area 2, Route 1, Sensor Set 1.

Table A.7. Case 5 - Node Linkage for Route

FROM	EASTING	NORTHING	TO	PENALTY	EASTING	NORTHING
3	3820	7280	9	1	4870	7630
9	4870	7630	13	1	4450	8470
13	4450	8470	7	50	5290	7630
7	5290	7630	-2	40	4240	7280
-2	4240	7280	11	202	4100	7980
11	4100	7580	31	17	2560	5870
31	2560	9870	37	2	3470	10640
17	3470	10640	32	37	4240	10080
32	4240	10080	36	52	5290	10640
16	5290	10640	35	160	4730	10430
35	4730	10430	46	54	5500	11270
46	5500	11270	38	105	6340	10710
38	6340	10710	33	36	5500	10150
33	5500	10150	-21	56	5010	9100
-21	5010	9100	12	34	5430	8190
12	5430	8190	22	38	5570	9170
22	5570	9170	26	90	3610	5660
26	3610	5660	19	60	4100	9100
19	4100	9100	-23	72	3120	9240
-23	3120	9240	23	3	4170	9240
23	4170	9240	42	34	2980	11060
42	2980	11060	34	64	2280	10360
34	2280	10360	56	58	2630	12320
56	2630	12320	50	29	3260	11550
50	3260	11550	57	116	3690	12390
57	3690	12390	-62	2	2640	13090
-62	2640	13090	70	166	2210	14000
70	2210	14000	82	88	2560	14910
82	2560	14910	-76	238	2510	14420
-76	2510	14420	-71	492	2700	13720
-71	2700	13720	-52	62	4660	11830
-52	4660	11830	45	62	5150	11270
45	5150	11270	65	10	7180	13230
65	7180	13230	71	20	6020	14140
71	6020	14140	79	66	6790	14560
79	6790	14560	61	190	9560	14770

Table A.8. Case 5 - Node Linkage

NODE NO. 3 TOTAL LINKS 5															
X,Y,Z COORDINATE	25,	4,	350												
LINKED TO	11	8	9	-2	-1										
EXPOSURE	75	148	0	148	206										
WEIGHTED	152	298	1	149	414										
NODE NO. 9 TOTAL LINKS 5															
X,Y,Z COORDINATE	41,	9,	290												
LINKED TO	7	12	11	13	-2										
EXPOSURE	147	75	65	0	137										
WEIGHTED	140	152	132	1	276										
NODE NO. 13 TOTAL LINKS 6															
X,Y,Z COORDINATE	25,	21,	290												
LINKED TO	11	19	23	12	7	-21									
EXPOSURE	124	79	87	53	24	156									
WEIGHTED	250	80	88	54	50	314									
NODE NO. 7 TOTAL LINKS 4															
X,Y,Z COORDINATE	47,	9,	300												
LINKED TO	12	-10	-2	-12											
EXPOSURE	100	234	19	218											
WEIGHTED	202	235	40	219											
NODE NO. -2 TOTAL LINKS 2															
X,Y,Z COORDINATE	32,	4,	310												
LINKED TO	11	-1													
EXPOSURE	100	176													
WEIGHTED	202	274													
NODE NO. 11 TOTAL LINKS 21															
X,Y,Z COORDINATE	30,	14,	300												
LINKED TO	19	23	8	12	18	28	22	32	31	-13					
LINKED TO	-1	-21	-23	-26	-3	-18	-10	-12	-24	-20					
LINKED TO	-27														
EXPOSURE	91	98	185	92	95	64	103	39	16	149					
EXPOSURE	195	134	91	276	209	217	238	240	145	243					
EXPOSURE	244														
WEIGHTED	184	198	372	93	94	65	208	80	17	300					
WEIGHTED	392	270	92	558	420	436	235	241	292	244					
WEIGHTED	490														
NODE NO. 31 TOTAL LINKS 6															
X,Y,Z COORDINATE	2,	41,	300												
LINKED TO	34	18	28	37	-24	-23									
EXPOSURE	100	64	19	0	225	80									
WEIGHTED	101	130	20	2	452	81									
NODE NO. 37 TOTAL LINKS 7															
X,Y,Z COORDINATE	21,	52,	300												
LINKED TO	42	40	37	28	-40	-41	-48								
EXPOSURE	100	40	36	28	255	182	98								
WEIGHTED	202	82	37	58	512	366	198								
NODE NO. 32 TOTAL LINKS 9															
X,Y,Z COORDINATE	32,	44,	300												
LINKED TO	35	28	23	19	36	-26	-40	-41	-21						
EXPOSURE	116	92	79	39	25	308	204	208	65						
WEIGHTED	234	186	150	80	52	309	410	418	132						
NODE NO. 36 TOTAL LINKS 12															
X,Y,Z COORDINATE	47,	52,	300												
LINKED TO	33	35	45	46	38	47	-32	-39	-41	-43					
LINKED TO	-27	-26													
EXPOSURE	152	89	160	110	181	166	272	281	285	180					
EXPOSURE	250	231													
WEIGHTED	310	160	322	238	1820	1670	271	484	412	1810					
WEIGHTED	502	464													
NODE NO. 35 TOTAL LINKS 7															
X,Y,Z COORDINATE	35,	40,	300												
LINKED TO	33	45	45	-41	-28	-40	-27								
EXPOSURE	111	123	26	268	304	223	238								
WEIGHTED	112	248	54	538	610	448	235								
NODE NO. 45 TOTAL LINKS 9															
X,Y,Z COORDINATE	50,	61,	320												
LINKED TO	45	47	34	-43	-23	-39	-50	-41	-32						
EXPOSURE	100	136	104	145	141	122	109	174	194						
WEIGHTED	202	1370	105	1440	1420	123	220	350	310						

Case 6 - Area 2, Route 2, Sensor Set 1.

Table A.9. Case 6 - Node Linkage for Route

FROM	EASTING	NORTHING	TO	PENALTY	EASTING	NORTHING
35	2770	10500	28	1	3610	9660
28	3610	9660	19	77	4100	9100
19	4100	9100	31	66	4240	10080
31	4240	10080	36	1P	5290	10640
36	5290	10640	34	180	4710	10430
34	4730	10430	46	54	5500	11270
46	5500	11270	36	105	6340	10710
38	6340	10710	32	36	5500	10150
32	5500	10150	-21	56	5010	9100
-21	5010	9100	11	34	5430	8190
11	5430	8190	12	10	4450	8470
12	4450	8470	22	96	4170	9240
22	4170	9240	42	51	2980	11060
42	2980	11060	33	64	2280	10360
33	2280	10360	-45	99	2070	11410
-45	2070	11410	56	2	2630	12320
56	2630	12320	50	29	3260	11550
50	3260	11550	37	46	3470	10640
37	3470	10640	30	2	2560	9870
30	2560	9870	15	2	2580	9030
15	2580	9030	9	7	4870	7630
9	4870	7630	10	2	4100	7980
10	4100	7980	-23	57	3120	9240
-23	3120	9240	-2	52	4240	7280
-2	4240	7280	7	1	5290	7630
7	5290	7630	-13	36	3190	8400
-13	3190	8400	-24	216	2280	9240
-24	2280	9240	-1	116	3190	7280
-1	3190	7280	8	292	2840	7630
8	2840	7630	52	44	2770	11760
52	2770	11760	57	156	3890	12390
57	3890	12390	-62	2	2840	12090
-62	2840	12090	70	166	2210	14000
70	2210	14000	81	68	2560	14910
81	2560	14910	-76	238	2910	14420
-76	2910	14420	-71	492	2700	13720
-71	2700	13720	-52	40	4660	11830
-52	4660	11830	45	82	5150	11270
45	5150	11270	65	10	7190	13230
65	7190	13230	71	20	8020	14140
71	8020	14140	79	66	6790	14560
79	6790	14560	66	1	9840	13510
66	9840	13510	61	48	10260	12670
61	10260	12670	67	1	9280	13720
67	9280	13720	-58	2	9840	12880
-58	9840	12880	69	91	10690	13860
69	10690	13860	62	2	10680	12810
62	10680	12810	68	56	11590	13860
68	11590	13860	76	41	10610	14420
76	10610	14420	84	246	10960	14980

Table A.10. Case 6 - Node Linkage

NODE NO. 35 TOTAL LINKS 8										
X,Y,Z COORDINATE 11, 50, 300										
LINKED TO	33	42	30	37	50	28	-42	-45		
EXPOSURE	100	86	77	69	4	0	141	103		
WEIGHTED	202	174	156	140	10	1	284	208		
NODE NO. 28 TOTAL LINKS 7										
X,Y,Z COORDINATE 23, 30, 300										
LINKED TO	22	19	31	15	37	30	-23			
EXPOSURE	134	76	121	137	66	47	195			
WEIGHTED	135	77	244	276	134	96	392			
NODE NO. 19 TOTAL LINKS 7										
X,Y,Z COORDINATE 30, 30, 290										
LINKED TO	22	12	31	-24	-21	-23	-13			
EXPOSURE	114	43	32	260	89	48	49			
WEIGHTED	234	86	66	522	90	98	100			
NODE NO. 31 TOTAL LINKS 8										
X,Y,Z COORDINATE 32, 44, 300										
LINKED TO	34	22	37	36	-26	-40	-41	-21		
EXPOSURE	100	62	45	8	308	204	207	58		
WEIGHTED	202	126	92	18	309	410	416	59		
NODE NO. 36 TOTAL LINKS 12										
X,Y,Z COORDINATE 47, 52, 300										
LINKED TO	32	34	45	46	38	47	-32	-39	-41	-43
LINKED TO	-27	-26								
EXPOSURE	154	89	160	118	181	166	272	201	205	180
EXPOSURE	250	231								
WEIGHTED	318	180	322	238	1820	1670	273	404	912	1810
WEIGHTED	502	464								
NODE NO. 34 TOTAL LINKS 7										
X,Y,Z COORDINATE 35, 49, 300										
LINKED TO	32	45	46	-41	-26	-40	-27			
EXPOSURE	111	123	26	268	304	223	238			
WEIGHTED	112	248	54	538	610	448	239			
NODE NO. 46 TOTAL LINKS 9										
X,Y,Z COORDINATE 50, 51, 320										
LINKED TO	45	47	35	-44	-53	-39	-52	-41	-32	
EXPOSURE	100	136	104	143	141	122	109	174	154	
WEIGHTED	202	1370	105	1440	1420	123	220	350	310	
NODE NO. 38 TOTAL LINKS 8										
X,Y,Z COORDINATE 62, 53, 340										
LINKED TO	47	42	27	-36	-32	-43	-37	-27		
EXPOSURE	195	17	246	232	271	200	320	237		
WEIGHTED	392	36	494	466	544	402	321	476		
NODE NO. 32 TOTAL LINKS 5										
X,Y,Z COORDINATE 50, 45, 330										
LINKED TO	21	-27	-32	-26	-35	-21	-43	-41		
EXPOSURE	49	337	291	287	196	27	145	147		
WEIGHTED	100	676	292	576	374	56	300	336		
NODE NO. -21 TOTAL LINKS 6										
X,Y,Z COORDINATE 43, 30, 330										
LINKED TO	21	12	22	11	-26	-27				
EXPOSURE	158	33	44	14	130	250				
WEIGHTED	159	66	98	34	662	502				
NODE NO. 11 TOTAL LINKS 7										
X,Y,Z COORDINATE 49, 17, 300										
LINKED TO	7	5	21	12	-12	-10	-20			
EXPOSURE	116	53	76	4	276	270	230			
WEIGHTED	234	108	154	10	277	271	462			
NODE NO. 12 TOTAL LINKS 5										
X,Y,Z COORDINATE 35, 21, 290										
LINKED TO	10	22	9	7	-10					
EXPOSURE	116	57	70	65	366					
WEIGHTED	234	98	142	132	367					

Table A.10. (cont'd.)

NODE NO. -51 TOTAL LINKS 12
 X,Y,Z COORDINATE 10, 96, 350
 LINKED TO 71 72 73 74 75 76 77 78 79 80 81 82
 EXPOSURE 162 163 170 171 172 173 174 175 176 177 178 179
 WEIGHTED 1130 1140 1150 1160 1170 1180 1190 1200 1210 1220 1230 1240

NODE NO. -52 TOTAL LINKS 6
 X,Y,Z COORDINATE 39, 69, 150
 LINKED TO 45 60 55 -48 -41 -40
 EXPOSURE 81 154 177 147 188 138
 WEIGHTED 82 310 1750 296 378 276

NODE NO. 45 TOTAL LINKS 21
 X,Y,Z COORDINATE 45, 61, 340
 LINKED TO 47 59 60 21 27 65 -41 -53 -43 -40
 LINKED TO -39 -48 -32 -26 -27 -54 -37 -60 -64 -61
 LINKED TO -59
 EXPOSURE 188 213 122 32 211 0 211 129 191 188
 EXPOSURE 183 118 242 224 233 311 250 321 225 311
 EXPOSURE 65
 WEIGHTED 1890 2140 246 66 212 10 424 1300 1920 378
 WEIGHTED 184 238 243 450 468 3120 251 3220 452 3120
 WEIGHTED 132

NODE NO. 65 TOTAL LINKS 9
 X,Y,Z COORDINATE 74, 89, 330
 LINKED TO 64 73 71 55 -56 -61 -56 -68 -54
 EXPOSURE 53 47 19 37 137 344 211 325 297
 WEIGHTED 54 48 20 380 138 690 2120 652 2980

NODE NO. 71 TOTAL LINKS 6
 X,Y,Z COORDINATE 86, 102, 300
 LINKED TO 80 73 79 64 -65 -66
 EXPOSURE 100 67 85 32 91 96
 WEIGHTED 202 136 86 330 92 970

NODE NO. 75 TOTAL LINKS 9
 X,Y,Z COORDINATE 97, 108, 300
 LINKED TO 67 77 80 89 53 66 -82 -69 -81
 EXPOSURE 74 140 91 345 276 0 300 94 243
 WEIGHTED 75 141 184 346 277 1 301 190 488

NODE NO. 66 TOTAL LINKS 9
 X,Y,Z COORDINATE 112, 93, 250
 LINKED TO 67 61 77 63 62 69 76 -72 -58
 EXPOSURE 77 33 166 116 103 102 131 190 164
 WEIGHTED 156 68 167 234 208 103 132 191 330

NODE NO. 61 TOTAL LINKS 6
 X,Y,Z COORDINATE 118, 81, 290
 LINKED TO 62 53 51 67 -58 -51
 EXPOSURE 190 140 37 0 188 55
 WEIGHTED 191 282 76 1 378 112

NODE NO. 67 TOTAL LINKS 5
 X,Y,Z COORDINATE 104, 96, 290
 LINKED TO 63 77 -72 -69 -58
 EXPOSURE 41 76 100 132 0
 WEIGHTED 84 77 101 266 2

NODE NO. -58 TOTAL LINKS 6
 X,Y,Z COORDINATE 112, 64, 300
 LINKED TO 63 62 51 69 -72 -51
 EXPOSURE 190 179 104 90 148 56
 WEIGHTED 382 180 210 91 149 114

NODE NO. 69 TOTAL LINKS 7
 X,Y,Z COORDINATE 127, 58, 300
 LINKED TO 76 68 78 62 -65 -63 -72
 EXPOSURE 140 114 158 0 331 195 15
 WEIGHTED 141 115 155 2 664 392 40

NODE NO. 62 TOTAL LINKS 6
 X,Y,Z COORDINATE 124, 83, 300
 LINKED TO 58 52 68 -63 -65 -51
 EXPOSURE 152 88 50 261 324 29
 WEIGHTED 306 178 56 262 325 60

Table A.10. (cont'd.)

NODE NO.	68	TOTAL LINKS	5
X,Y,Z COORDINATE	137.	98.	300
LINKED TO	78	76	-65 -73 -63
EXPOSURE	223	40	346 319 215
WEIGHTED	224	41	694 640 432

NODE NO.	76	TOTAL LINKS	7
X,Y,Z COORDINATE	122.	106.	300
LINKED TO	84	77	78 -72 -80 -84 -65
EXPOSURE	245	119	173 69 267 289 222
WEIGHTED	246	60000	52200 49000 28800 87000 111500

Case 7, Area 2, Route 1, Sensor Set 2.

Table A.11. Case 7 - Node Linkage for Route

FROM	EASTING	NORTHING	TO	PENALTY	EASTING	NORTHING
3	3820	7280	9	2	4870	7630
9	4870	7630	13	1	4450	8470
13	4450	8470	7	50	5290	7630
7	5290	7630	-2	40	4240	7280
-2	4240	7280	11	101	4100	7980
11	4100	7980	31	17	2560	9870
31	2560	9870	37	1	3470	10640
37	3470	10640	50	41	3260	11550
50	3260	11550	56	22	2630	12320
56	2630	12320	-59	159	3610	12550
-59	3610	12950	-71	80	2700	13720
-71	2700	13720	-78	48	3540	14560
-78	3540	14560	-79	1	4590	15120
-79	4590	15120	87	89	5150	15470
87	5150	15470	90	39	6060	15540
90	6060	15540	83	9	6900	14980
83	6900	14980	80	26	7610	14700
80	7610	14700	79	34	8790	14560
79	8790	14560	81	180	9560	14770

Table A.12. Case 7 - Node Linkage

NODE NO. 3 TOTAL LINKS 5										
X,Y,Z COORDINATE	26,	4,	350							
LINKED TO	11	8	9	-2						-1
EXPOSURE	75	107	0	148						166
WEIGHTED	76	216	2	298						334
NODE NO. 9 TOTAL LINKS 5										
X,Y,Z COORDINATE	41,	9,	290							
LINKED TO	7	12	11	13						-2
EXPOSURE	147	75	65	0						137
WEIGHTED	296	152	132	1						276
NODE NO. 13 TOTAL LINKS 6										
X,Y,Z COORDINATE	35,	21,	290							
LINKED TO	11	19	23	12						7
EXPOSURE	124	79	87	53						24
WEIGHTED	250	80	88	108						314
NODE NO. 7 TOTAL LINKS 4										
X,Y,Z COORDINATE	47,	9,	300							
LINKED TO	12	-10	-2	-12						
EXPOSURE	100	265	15	248						
WEIGHTED	202	532	40	498						
NODE NO. -2 TOTAL LINKS 2										
X,Y,Z COORDINATE	32,	4,	310							
LINKED TO	11	-1								
EXPOSURE	100	96								
WEIGHTED	101	194								
NODE NO. 11 TOTAL LINKS 21										
X,Y,Z COORDINATE	30,	14,	300							
LINKED TO	19	23	8	12	18	28	22	32	31	-13
LINKED TO	-1	-21	-23	-26	-3	-18	-10	-12	-24	-20
LINKED TO	-27									
EXPOSURE	91	58	144	92	95	64	183	39	16	149
EXPOSURE	155	134	91	218	176	175	269	271	148	270
EXPOSURE	183									
WEIGHTED	92	99	290	186	96	65	208	48	17	300
WEIGHTED	312	270	92	219	354	352	540	544	298	542
WEIGHTED	368									
NODE NO. 31 TOTAL LINKS 6										
X,Y,Z COORDINATE	8,	41,	300							
LINKED TO	34	18	22	37	-24	-23				
EXPOSURE	100	64	14	0	228	80				
WEIGHTED	101	130	40	1	458	81				
NODE NO. 37 TOTAL LINKS 7										
X,Y,Z COORDINATE	21,	52,	300							
LINKED TO	42	58	32	28	-48	-41	-42			
EXPOSURE	100	48	36	28	259	183	166			
WEIGHTED	202	41	74	58	256	368	167			
NODE NO. 50 TOTAL LINKS 6										
X,Y,Z COORDINATE	18,	69,	300							
LINKED TO	52	42	56	57	-48	-48				
EXPOSURE	100	93	18	58	219	193				
WEIGHTED	202	188	22	59	448	388				
NODE NO. 56 TOTAL LINKS 4										
X,Y,Z COORDINATE	9,	76,	300							
LINKED TO	52	-42	-45	-59						
EXPOSURE	100	214	165	158						
WEIGHTED	202	219	332	159						
NODE NO. -59 TOTAL LINKS 5										
X,Y,Z COORDINATE	23,	85,	350							
LINKED TO	57	68	-62	-64	-71					
EXPOSURE	100	147	165	187	39					
WEIGHTED	101	256	332	188	88					
NODE NO. -71 TOTAL LINKS 5										
X,Y,Z COORDINATE	18,	96,	350							
LINKED TO	78	-62	-76	-74	-78					
EXPOSURE	100	236	128	129	47					
WEIGHTED	202	237	121	138	48					

Table A.12. (cont'd.)

NODE NO. -78 TOTAL LINKS 6										
X,Y,Z COORDINATE 22, 108, 340										
LINKED TO	84	75	82	-74	-76	-79				
EXPOSURE	90	70	17	195	112	0				
WEIGHTED	91	71	36	392	226	1				
NODE NO. -79 TOTAL LINKS 9										
X,Y,Z COORDINATE 37, 116, 330										
LINKED TO	86	67	72	75	84	74	96	-85	-74	
EXPOSURE	100	68	90	90	80	62	44	98	96	
WEIGHTED	101	69	91	182	162	126	90	91	194	
NODE NO. 87 TOTAL LINKS 6										
X,Y,Z COORDINATE 45, 121, 320										
LINKED TO	86	85	90	-85	-88	-75				
EXPOSURE	132	40	38	119	105	96				
WEIGHTED	133	41	39	240	110	194				
NODE NO. 90 TOTAL LINKS 6										
X,Y,Z COORDINATE 56, 122, 310										
LINKED TO	85	91	86	83	-88	-77				
EXPOSURE	132	103	77	8	121	96				
WEIGHTED	133	104	156	9	244	194				
NODE NO. 83 TOTAL LINKS 8										
X,Y,Z COORDINATE 70, 114, 300										
LINKED TO	91	73	88	85	80	-77	-81	-75		
EXPOSURE	124	98	91	63	35	138	52	97		
WEIGHTED	250	158	92	128	36	278	54	196		
NODE NO. 80 TOTAL LINKS 6										
X,Y,Z COORDINATE 83, 110, 300										
LINKED TO	71	73	88	79	89	-81				
EXPOSURE	100	165	133	33	154	156				
WEIGHTED	202	212	268	34	155	157				
NODE NO. 79 TOTAL LINKS 10										
X,Y,Z COORDINATE 97, 108, 200										
LINKED TO	81	71	67	77	89	93	66	-82	-69	-81
EXPOSURE	179	108	124	135	207	191	51	271	94	109
WEIGHTED	180	76300	37500	13620	62400	19200	15600	816	47500	55000

Case 8 - Area 2, Route 2, Sensor Set 2.

Table A.13. Case 8 - Node Linkage for Route

FROM	EASTING	NORTHING	TO	PENALTY	EASTING	NORTHING
35	2770	10500	28	1	3610	9660
28	3610	9660	37	67	3470	10640
37	3470	10640	30	2	2560	9870
30	2560	9870	15	50	2560	9030
15	2560	9030	9	7	4870	7630
9	4870	7630	12	1	4450	8470
12	4450	8470	7	50	5290	7630
7	5290	7630	-2	40	4240	7280
-2	4240	7280	10	101	4100	7980
10	4100	7980	31	37	4240	10080
31	4240	10080	36	52	5290	10640
36	5290	10640	46	119	5500	11270
46	5500	11270	34	8	4730	10430
34	4730	10430	32	156	5500	10150
32	5500	10150	-21	56	5010	9100
-21	5010	9100	11	34	5430	8190
11	5430	8190	21	19	5570	9170
21	5570	9170	19	110	4100	9100
19	4100	9100	-23	72	3120	9240
-23	3120	9240	22	18	4170	9240
22	4170	9240	42	34	2980	11060
42	2980	11060	33	64	2280	10360
33	2280	10360	56	34	2630	12320
56	2630	12320	50	29	3260	11550
50	3260	11550	57	59	3890	12390
57	3890	12390	-62	110	2840	13090
-62	2840	13090	70	2	2210	14000
70	2210	14000	81	1	2560	14910
81	2560	14910	96	1	3610	15960
96	3610	15960	105	1	4660	17010
105	4660	17010	91	1	6620	15540
91	6620	15540	88	55	7670	15470
88	7670	15470	63	22	6500	14580
63	6500	14580	60	46	7610	14700
60	7610	14700	79	34	8790	14560
79	8790	14560	66	52	9840	13510
66	9840	13510	76	144	10610	14420
76	10610	14420	84	191	10560	14580

Table A.14. (cont'd.)

NODE NO. 46 TOTAL LINKS 10
 X,Y,Z COORDINATE 50, 61, 320
 LINKED TO 45 47 38 34 -42 -53 -35 -52 -41 -32
 EXPOSURE 257 215 187 3 223 230 204 190 162 164
 WEIGHTED 516 2160 1880 8 2240 231 2050 362 366 330

NODE NO. 34 TOTAL LINKS 6
 X,Y,Z COORDINATE 39, 49, 300
 LINKED TO 32 45 -41 -26 -40 -27
 EXPOSURE 78 185 267 242 222 175
 WEIGHTED 158 186 268 486 446 352

NODE NO. 32 TOTAL LINKS 9
 X,Y,Z COORDINATE 50, 45, 330
 LINKED TO 21 38 -27 -32 -26 -39 -21 -43 -41
 EXPOSURE 49 183 275 224 227 190 27 151 167
 WEIGHTED 100 1840 552 2250 456 1910 56 1520 336

NODE NO. -21 TOTAL LINKS 6
 X,Y,Z COORDINATE 43, 30, 330
 LINKED TO 21 22 19 11 -26 -27
 EXPOSURE 158 48 15 16 271 189
 WEIGHTED 318 98 40 34 272 380

NODE NO. 11 TOTAL LINKS 4
 X,Y,Z COORDINATE 45, 17, 300
 LINKED TO 21 -12 -10 -20
 EXPOSURE 18 346 335 254
 WEIGHTED 19 694 680 510

NODE NO. 21 TOTAL LINKS 23
 X,Y,Z COORDINATE 51, 31, 350
 LINKED TO 27 13 22 19 38 45 2 3 -27 -20
 LINKED TO -26 -12 -32 -10 -35 -8 -15 -28 -37 -43
 LINKED TO -41 -40 -34
 EXPOSURE 337 321 74 54 214 183 76 69 278 354
 EXPOSURE 254 321 233 309 212 288 300 312 220 193
 EXPOSURE 190 175 195
 WEIGHTED 3380 644 150 110 2150 184 154 140 558 710
 WEIGHTED 510 644 2340 620 2130 578 3010 3130 2210 1940
 WEIGHTED 191 176 1960

NODE NO. 19 TOTAL LINKS 4
 X,Y,Z COORDINATE 30, 30, 250
 LINKED TO 22 -26 -23 -13
 EXPOSURE 100 200 35 39
 WEIGHTED 101 402 72 80

NODE NO. -23 TOTAL LINKS 4
 X,Y,Z COORDINATE 16, 32, 310
 LINKED TO 22 -24 -13 -18
 EXPOSURE 8 228 137 146
 WEIGHTED 18 458 276 294

NODE NO. 22 TOTAL LINKS 21
 X,Y,Z COORDINATE 21, 32, 300
 LINKED TO 8 42 33 45 47 -26 -13 -27 -40 -41
 LINKED TO -24 -20 -18 -1 -32 -12 -10 -39 -3 -42
 LINKED TO -43
 EXPOSURE 96 33 32 187 167 270 113 235 216 219
 EXPOSURE 175 300 186 91 196 279 271 183 156 156
 EXPOSURE 171
 WEIGHTED 194 34 66 188 1680 542 228 472 217 220
 WEIGHTED 352 602 374 184 394 560 272 1848 314 314
 WEIGHTED 1720

NODE NO. 42 TOTAL LINKS 7
 X,Y,Z COORDINATE 14, 30, 300
 LINKED TO 50 52 33 -42 -45 -40 -48
 EXPOSURE 100 73 31 205 183 189 166
 WEIGHTED 101 74 64 412 368 380 167

NODE NO. 33 TOTAL LINKS 11
 X,Y,Z COORDINATE 4, 40, 300
 LINKED TO 52 40 36 57 -42 -45 -24 -18 -40 -48
 LINKED TO -13
 EXPOSURE 61 58 33 58 249 233 210 196 205 190
 EXPOSURE 62
 WEIGHTED 62 59 34 59 250 234 422 394 412 191
 WEIGHTED 126

NODE NO. 56 TOTAL LINKS 4
 X,Y,Z COORDINATE 9, 76, 300
 LINKED TO 52 58 -62 -45 -59
 EXPOSURE 100 28 214 165 158
 WEIGHTED 202 29 215 332 159

Table A.14. (cont'd.)

NODE NO. 50 TOTAL LINKS 4
 X,Y,Z COORDINATE 18, 65, 300
 LINKED TO 52 57 -48 -40
 EXPOSURE 100 58 219 193
 WEIGHTED 202 59 440 388

NODE NO. 57 TOTAL LINKS 6
 X,Y,Z COORDINATE 27, 77, 330
 LINKED TO 60 -59 -48 -52 -64 -62
 EXPOSURE 172 160 143 122 191 54
 WEIGHTED 173 322 288 244 192 110

NODE NO. -62 TOTAL LINKS 3
 X,Y,Z COORDINATE 12, 87, 350
 LINKED TO 70 -71 -59
 EXPOSURE 0 155 226
 WEIGHTED 2 156 454

NODE NO. 70 TOTAL LINKS 3
 X,Y,Z COORDINATE 3, 100, 330
 LINKED TO #1 -71 -76
 EXPOSURE 0 195 86
 WEIGHTED 1 392 87

NODE NO. 81 TOTAL LINKS 6
 X,Y,Z COORDINATE 8, 113, 330
 LINKED TO 95 #2 96 -76 -78 -74
 EXPOSURE 57 49 0 147 97 127
 WEIGHTED 116 50 1 296 98 256

NODE NO. 96 TOTAL LINKS 8
 X,Y,Z COORDINATE 23, 128, 330
 LINKED TO 82 102 95 105 -93 -85 -92 -79
 EXPOSURE 63 149 54 0 190 54 140 24
 WEIGHTED 64 150 110 1 382 55 282 50

NODE NO. 105 TOTAL LINKS 13
 X,Y,Z COORDINATE 38, 143, 330
 LINKED TO 87 86 90 85 82 95 91 -85 -88 -93
 LINKED TO -79 -95 -92
 EXPOSURE 81 62 28 13 59 53 0 148 137 128
 EXPOSURE #6 121 96
 WEIGHTED 164 126 29 28 128 188 1 149 138 258
 WEIGHTED 87 244 194

NODE NO. 51 TOTAL LINKS 6
 X,Y,Z COORDINATE 66, 122, 310
 LINKED TO 90 #3 85 88 -87 -77
 EXPOSURE 124 #7 95 58 180 73
 WEIGHTED 250 176 192 59 181 148

NODE NO. 88 TOTAL LINKS 6
 X,Y,Z COORDINATE 21, 121, 320
 LINKED TO 80 #3 89 -81 -87 -90
 EXPOSURE 29 10 116 139 146 150
 WEIGHTED 60 22 117 140 294 151

NODE NO. 83 TOTAL LINKS 7
 X,Y,Z COORDINATE 70, 114, 300
 LINKED TO 73 85 80 90 -77 -81 -79
 EXPOSURE 124 76 47 56 161 54 97
 WEIGHTED 250 154 48 114 324 55 196

NODE NO. 80 TOTAL LINKS 5
 X,Y,Z COORDINATE 83, 110, 308
 LINKED TO 71 73 79 89 -81
 EXPOSURE 108 105 33 154 156
 WEIGHTED 202 212 34 155 157

NODE NO. 79 TOTAL LINKS 9
 X,Y,Z COORDINATE 97, 108, 300
 LINKED TO 71 67 77 89 93 66 -82 -69 -81
 EXPOSURE 108 124 135 207 191 51 271 94 109
 WEIGHTED 218 125 136 208 192 52 272 198 220

Table A.14. (cont'd.)

NODE NO.	66	TOTAL LINKS		9						
X,Y,Z COORDINATE	112.	93.	290							
LINKED TO	67	61	77	63	62	69	76	-72	-58	
EXPOSURE	127	100	160	174	234	157	143	238	289	
WEIGHTED	256	202	161	350	470	158	144	239	580	

NODE NO.	76	TOTAL LINKS		9						
X,Y,Z COORDINATE	123.	106.	300							
LINKED TO	69	84	77	78	68	-72	-80	-84	-65	
EXPOSURE	155	190	110	181	131	113	233	205	187	
WEIGHTED	780	191	55500	54600	39600	79800	23400	61800	94000	

APPENDIX B

FORTRAN PROGRAM FOR ROUTING MODEL

The program that has been developed as a result of this research is currently running on a CDC Cyber 7400 series machine. The programmed model has been tested on a ten kilometer area and was run for a 35 by 35 km area. The longest running feature of the model is the line of sight calculations. The model has 14 subroutines which are controlled by the main program and one subroutine. The relationship between the subroutines is shown in Figure B-1.

Within this appendix is a short discussion of the model. The basic purpose and operations of the various subroutines are given first. The arrays in COMMON and those that are not are defined. Also variables within COMMON are defined along with some which are used only in a single subroutine. With one exception, flow charts were not drawn for the model since the definition of the variables and the comments within the program itself should be sufficient. The logic of subroutine CLUST is not obvious, therefore a flow chart was drawn for this subroutine. Lastly, within this appendix is a listing of the Fortran computer code for the 10 by 10 km size model.

Main Program

The main program is an executive routine that directs the operation of the model. Five subroutines are called by the main program. The initial call is to INDATA which is a short subroutine that reads the terrain data. After this call the main program groups this elevation

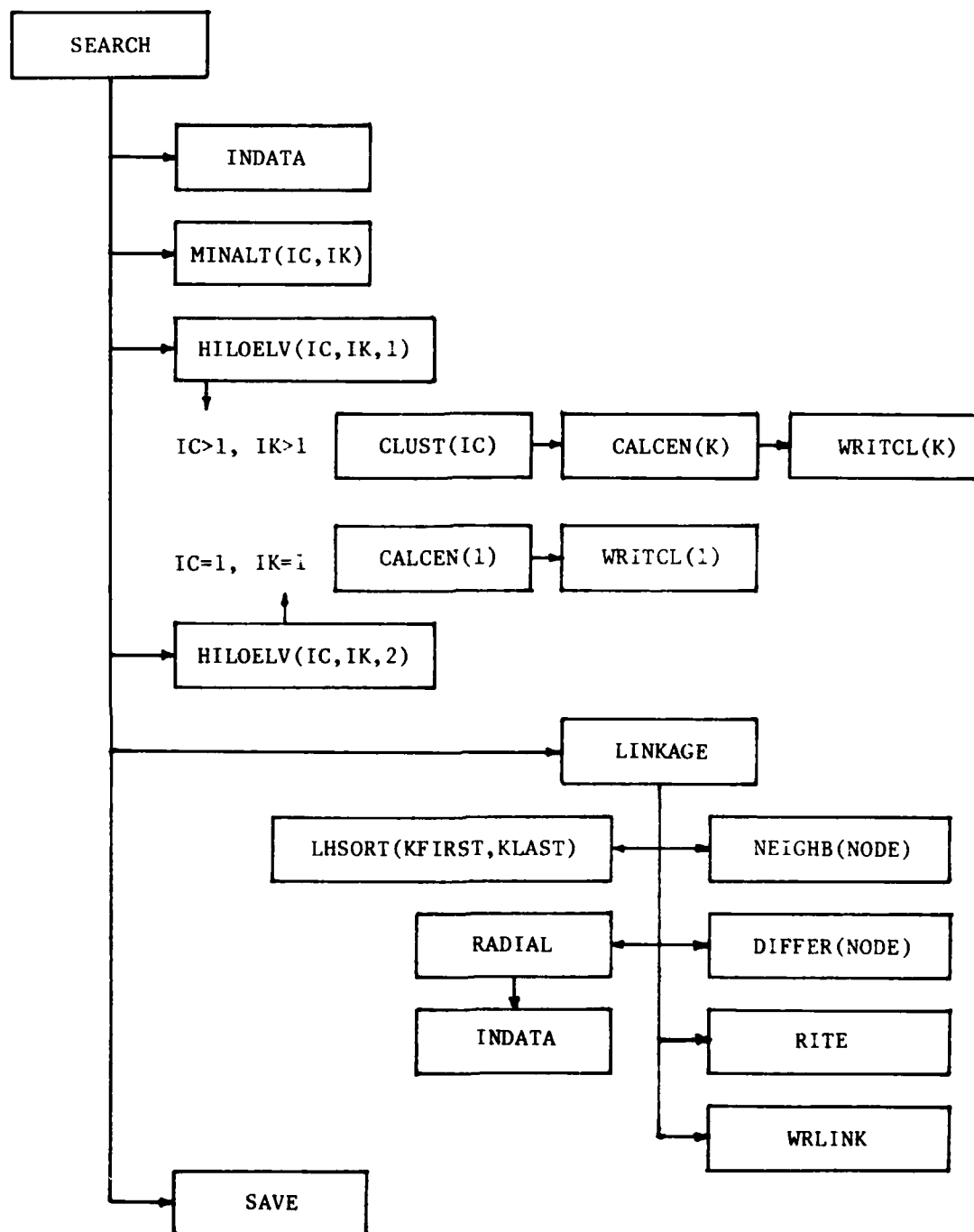


Figure B-1. Main Program and Subroutine Relationship.

data into elevation bands. Each sensor site's elevation is obtained from this data by finding the sensor's location within the elevation data array. A call is then made to the MINALT subroutine to determine both the maximum and minimum elevation groups within each elevation data array of 1 km square. Two calls are made to HILOELV subroutine; the first call is for processing the low elevation band and the second call is for the high elevation band. The next subroutine called is LINKAGE which is an executive subroutine that directs the routing process. If the results of route development are to be retained for further use, then SAVE can be called.

INDATA

This subroutine only reads the elevation data for the model. The terrain data is read in strips of 1 km wide and up to 50 km long. The data is stored into arrays of 15 by 15 data points and have a terrain interval of 70 meters between points. As each new strip of terrain is needed, a call is made to this subroutine.

MINALT

The minimum and maximum elevation data points in an array are found and stored in arrays in a packed format. The array ISET contains the row and column index of each low point and the array MSET contains the high points. The data is processed sequentially from the first terrain data array element such that if a new minimum or maximum is found, the pointers and counter are reset.

HILOELV

This subroutine is divided into two major parts. An IF test is performed on a call parameter ILO to determine whether the low

elevation (IC, — ,ILO=1) or high elevation data (— ,IK,ILO=2) is processed. The logic is the same for each part. A call is made to CLUST which identifies disjoint groups of elevation data. After finding the members of each cluster a call is made to CALCEN to calculate the cluster center. If there is only a single value in this cluster, CLUST is skipped and CALCEN is called directly. The values on these centers are then stored in LOWCEN or HICEN depending on which type of elevation data is being processed. After storing these values a return is made to the main program.

CLUST

Once the low or high data points are identified the cluster to which they belong is determined by the beginning and end of each data point string. The data points have been found sequentially; therefore, the breaks in adjacency of points define the cluster boundaries. Since the row and column indexes are stored by letting $IVAL = (ROW * 100) + COLUMN$, subtracting two consecutive values will indicate whether they are adjacent. When all the members of a cluster are found, a call is made to CALCEN to calculate the centroid of the cluster.

CALCEN

This subroutine calculates the centroid of the cluster found in CLUST. The mean of row indexes (\bar{Y}) and mean of column indexes (\bar{X}) are the values for the center of the cluster. Since the indexes are integer values, the sum of the indices has a half added to allow for truncation of the decimal portion. An IF test is made on the calculated indexes for the center to ensure that they are within the array dimensions. For debug purposes several write statements in this subroutine can be set.

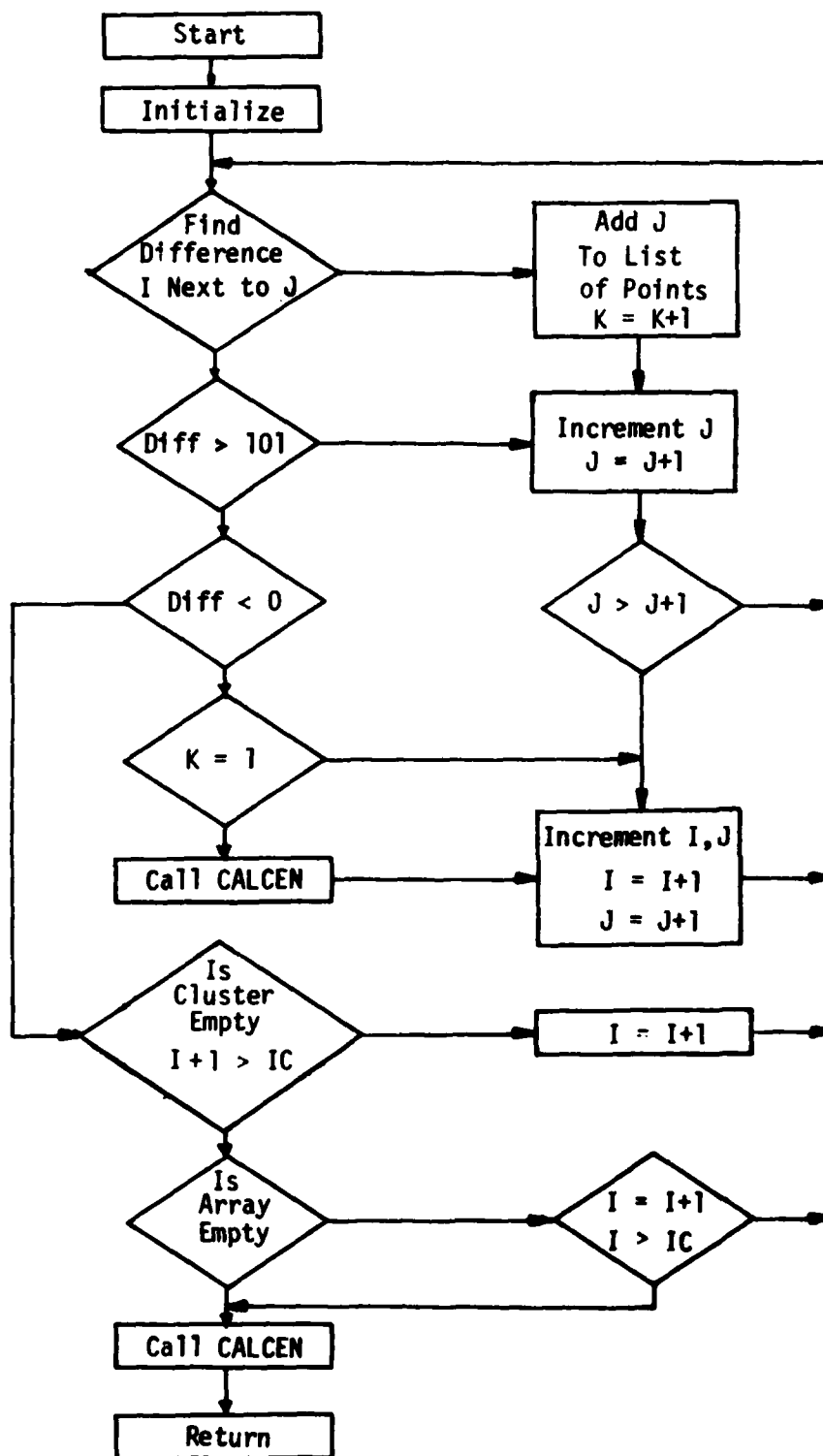


Figure B-2. Subroutine CLUST.

WRITCL

To list the clusters and centers this subroutine can be called letting $LWRIT \geq 3$. The low (or high) elevation cluster and pointers to the cluster members are listed. When this routine is called, LH is checked to decide whether high or low elevation values are to be printed.

LINKAGE

Once all the high and low elevation centers have been found, the main program calls this subroutine. The remaining portion of the model is directed by LINKAGE. The first subroutine it calls is LHSORT to sort the high and low lists of centers. Then subroutine RADIAL is called to determine the LOS between each node point and each sensor. RADIAL also calculates the first part of the penalty function.

The routine now processes each route node by finding all other node points which are within 1 km. These other nodes are the neighborhood of points that have possible links between them and the current node being evaluated. Two arrays, LINK and LINKTO, are used to store which nodes are in the neighborhood, the penalty value associated with the nodes and a beginning of the list for each node. The high nodes are identified by a minus sign. Having defined the neighborhoods and penalty values for each point in the neighborhood, the route node is selected. Control is then returned to the main program.

RADIAL

This subroutine is the most time consuming of the model. To determine visibility of two terrain points requires more effort than would seem to be necessary. The first problem is to locate where the two points are in the terrain data base. Along the vector connecting

these points a search is made for any terrain feature that would block the line of sight.

The subroutine first determines whether the sensor or the node is the westernmost point. If necessary the logic will swap the two points to set the node as the western point and the sensor as the eastern point. Having established the ends of the LOS vector, the tangent from the horizontal and the sine and cosine are calculated.

With those parameter values the routine begins the search along the vector. The vector is tested to locate its direction. Depending on whether it's between 0° - 45° , 45° - 135° , or 135° - 180° will give a heading of north, east or south respectively. The calculations used are given in section 4.3.

The routine finishes by listing the exposure values calculated for the number of sensors that can see each node. These values will then be used by DIFFER for those nodes which lie along the route corridor.

LHSORT

The initial point and the terminal point are added to the list of low elevation centers. The low elevation centers (nodes) are sorted into ascending order by row. This sorting is to ease the logic for the model. After the low centers are finished the high elevation centers are sorted in the same manner. Pointers KFIRST and KLAST are used to locate the initial and terminal nodes and are set after the sorting of LOWCEN. The lists of low and high nodes are written out as tables before returning to LINKAGE.

NEIGHB

To define a neighborhood it was found that the normal visual search pattern is limited to 1 km. The nodes which lie within 1 km are considered

to be neighbors of the current node. The resulting area is a 2 km square with the principle node in the center. Having sorted the arrays of centers, only 15 rows in either direction from the current row are searched for a neighbor. For any row that is searched, only those nodes which are within 15 columns on either side of the current node are retained as neighbors. When both the low and high centers that are in the neighborhood have been found, they are stored for use by subroutine DIFFER. The results can be listed by having LWRIT \geq 2.

DIFFER

For each neighborhood the distance from the current (primary) node is calculated and stored. The DIST array retains the distances for low centers in the first column and the high centers in the second column. The minimum and maximum distance and elevation are found while the distance between node points is calculated. Once these values are obtained they are sorted in ascending order by distance. A value of LWRIT \geq 2 will allow the printing of these results. The routine then completes the calculation of the exposure value for these nodes using the values stored by RADIAL.

RITE

This routine will write several of the large arrays to temporary storage if there are more values than the arrays can handle. These data are then read back into the program as needed on top of those values no longer needed.

SAVE

This routine will save the route and linkage arrays for plotting. A TAPE 7 is set up to store the data in a format for plotting the X-Y

coordinates of the nodes. The routine can be easily modified to write any data that should be retained.

WRLINK

After the route has been found, this routine will list the linkage information used in constructing the route. Listed are the arrays, the pointers and nodes with their exposure values.

Arrays in COMMON

IDATA(I,J,K)	This array contains terrain elevation values. It is a three dimensional array where the index K indicates the map sheets. The initial values are reassigned based on the equation given in section 4.2
LOWCEN(I,J,K)	The X, Y and Z coordinate of the low elevation nodes are stored in this array. Index I contains the Y value, J contains the X value, and K contains the Z value.
HICEN(I,J,K)	This array is just like LOWCEN except it contains the X, Y and Z coordinate of the high elevation nodes.
IPOINT(I)	This array is used throughout the model to store pointers.
ISSET(I)	The row and column indexes of each cluster member are packed into this array. The first time used it contains low elevation points. The second time it contains the high elevation points.
MSET(I)	This array stores the high elevation cluster members for use by ISET.
CERIOD(X,Y,Z)	As the centers for the low and high centers are being calculated CERIOD is used to temporarily store them before placing them in either LOWCEN or HICEN.
ISITE(I,J,K)	The location of the sensors are stored in this array. Up to 10 sensors can be used as currently dimensioned.
INITIAL(I)	The location of the starting point for the route is entered into this array.
LAST(I)	The terminal point for the route is stored in this array.
LINK(I)	This array contains the pointers to the entries of LINKTO. The value in location I gives the beginning of the node list in LINKTO that is associated with node I of array FROM.

LINKTO(I,J,K) This array has the node number of the nodes linked to node I of FROM. J is the exposure value of that node and K is the weighted exposure value.

FROM(I) The route nodes are stored in order of occurrence in this array. If I is the tenth entry then this node number is the tenth node of the route.

TO(I,J) The first entry I contains the node that is reached from the FROM(I) node. The value stored in J is the weighted exposure for the node traveled to FROM(I).

DETLO(I) The visibility value for a low elevation node is stored in this array.

DETHI(I) The visibility value for a high elevation node is contained in this array.

DIST(I,J) The distance between a primary route node and the neighborhood nodes are stored in DIST. The I value is for low elevation nodes and the J value is for high elevation nodes.

SYSR(I) This array has the weapon system kill radius in km. This value is converted to the units used by the model. If the first value is zero, then radar avoidance weighting is not used.

SR(I,J) The range between the current node and the sensor, the angle to the sensor and the angle of coverage are stored in this array. This information is used for the radar avoidance weighting.

Arrays not in COMMON

MPOINT(I) For small lists which need pointers this array is set equivalent to the last part of IPOINT to save core storage. This array is used in several subroutines in this manner.

IFINISH(I) To keep up with the progress of the LOS calculations in RADIAL, this array has the bits of an array element set to one as each node-sensor pair is completed. The zero through nine bit are used for low elevation nodes and up to 10 sensors. The ten through nineteen bit are used for high elevation nodes.

NLIST(I) After the route is found, the smoothing routine stores the modified route in this array.

Variables in COMMON

JSTRIP	The current map sheet that is being used by the model.
KCET	The number of clusters that are found is stored in this variable until it can be added to either NLOW or NHI depending on whether it is low or high elevation clusters.
NLOW	This variable is the total number of low elevation nodes found plus the initial and final route nodes.
NHI	The total number of high elevation nodes found is stored in this variable.
SMAX	As the node-sensor combinations are being processed the maximum distance is checked. If a distance is found which is greater than SMAX then the new value is assigned to SMAX.
NBLKS	This variable is the number of data blocks written on to temporary storage.
LWRIT	This variable is used to obtain detail data on the operations of the model. It is mainly used for checking results. IF LWRIT > 5 then everything is printed. As this variable increases in value the amount of printing decreases. A value over 3 turns off the detail printing.
LDEBG	To debug the clustering portion of the model this variable can be set \neq 1.
LALT	The minimum elevation for the map sheet currently being used.
HALT	The maximum elevation for the current map sheet.
LH	If LH is set to 1 then low elevation points are being processed. IF LH is 2 then high elevation points are being processed.
SENALT	The altitude of the sensor above local terrain is entered in this variable.
VEHALT	The vehicle altitude it will be flying above local terrain. Can be used for a ground vehicle by setting it to zero.
NSITE	The number of sensors that are located in the area of interest. A maximum of ten can currently be used.

RE	This variable is the radius of the earth for use in the LOS calculations to allow for earth curvature.
MDIM	This variable is the number of data points in the terrain data array. It is now set for a 15 by 15 array.
GRID	The grid interval (in meters) between the terrain data points. From this research the grid interval was 70 meters.
SWEA	The easting of the southwest corner of the terrain area being analyzed.
SWNR	The northing of the southwest corner.
LTRS	The UTM letter designation for the grid zone of the southwest corner.
IRADUS	The radius value to be used to determine a neighborhood of nodes. A value of 15 (1 km) is currently being used.
LNEBR	The number of low elevation nodes within the neighborhood for the current route node being evaluated.
KNEBR	The number of high elevation nodes within the neighborhood.
IROW	The row value (y-axis) of the current route node being evaluated.
JCOL	The column (x-axis) of the current route node being evaluated.
KFIRST	The location of the initial route node within the LOWCEN array.
KLAST	The location of the terminal or destination node within the LOWCEN array.
IC	The number of nodes that the route passes through.
IFREE	The total number of linkages that were found as the route was being developed.
RANGE	The range at which the weighting scheme narrows the search area down. When the terminal point is within 1 km of the current position the field of view is narrowed down to 90°. Node points outside these parameters have a higher weight assigned to them.

KMAT	The maximum number of terrain data arrays in the north-south direction is assigned this variable.
ISTRIP	This variable is set equal to the number of map sheets being used.
JMAT	The current array within a map sheet that is being used by the model.
RATE	The distance between terrain points in the data base that are being used. In this research every data point is used thus RATE is set to one.

Subroutine RADIAL Variables

NORTH SOUTH EAST WEST	These variables are the map sheet boundaries and the names correspond to the boundary edge.
ZCURVE	This parameter is a logical value that be set if curvature of the earth is used for LOS calculations.
DZ	The amount of curvature that is present when correcting for earth curvature.
XSIT,XP YSIT,YP ZSIT,ZP KSIT	These variables are the X, Y and Z coordinates of the sensor that is currently being used in the LOS calculations. The KSIT value is the integer value of XSIT.
XS1 YS1 ZS1 KS1	These variables are the X, Y and Z coordinates of the current node being processed by RADIAL. The KS1 is the integer value of XS1.
XSP YSP ZSP	The difference between the sensor and node are found for each coordinate and stored in these variables.
DIS RMAX	This variable is the vector distance between the sensor and node in the X-Y plane. RMAX is set equivalent to DIS.
R	This variable is the vector distance from the node to the terrain point in the data base that LOS is being checked.
TM	The tangent to the eastern point from the horizontal is stored in this variable.
T	The tangent to the terrain is calculated and stored in variable for comparison with TM.
YWEST	The Y component of the tangent T on the west map edge is contained in this variable to correct for vector crossing map sheets.
Z	The elevation of the current terrain point being checked for masking is assigned to this variable.

XSIN	The sine of the azimuth angle measured clockwise from north for the node-sensor vector is stored in this variable.
YCOS	This variable is the cosine of the azimuth angle.
ZNORTH ZSOUTH	These variables are logicals to indicate whether the vector is heading north or south.
NAR	This variable is the array within the map sheet where the terrain point is located.
X,IX	These variables are the x coordinate for the current terrain point.
Y,JY	These variables are the y coordinate for the current terrain point.
IDX,JDY	These variables are the increment in X and Y respectively.
IFIN	This variable is used to check for completion of a sensor-node pair.
IEXP	The sensor bit in IFINISH is set by using the exponent of 2 corresponding to the bit location in the computer word.
RTOD	This variable is the number of radians to degrees.
EAST1 NORTH1	The easting and northing of the beginning of a route segment or path leg along the route.
EAST2 NORTH2	The easting and northing of the end node of the route segment that begins at EAST1,NORTH1.

Subroutine DIFFER Variables

DMIN	The minimum distance between any node in the neighborhood of the current route node being processed.
DMAX	The maximum distance between any node in the neighborhood of the current route node being evaluated.
DRANG	The difference between DMAX and DMIN is assigned this variable.
KZMIN	The minimum elevation for any node in the neighborhood for the route node being evaluated.

KZMAX The maximum elevation for any node in the neighborhood for the route node being evaluated.

KZRANG The difference of KZMAX less KZMIN is assigned this variable.

Subroutine LINKAGE Variables

NWEIG This variable is the weight a node point has because of its location with respect to the current route node.

IFLAG If the procedure cannot find any node points in a neighborhood of a route point, the rectilinear distance for a neighborhood is doubled. IFLAG is then set to -1 and the model stops if no nodes still cannot be found.

NPEN This variable is the weight exposure value the penalty function calculates for the node in the neighborhood.

LPEN This variable is used to store the current minimum NPEN that has been found.

NEWPT The node in the neighborhood with the current minimum exposure is assigned to NEWPT.

XI,IX The X coordinate difference between the route node and the neighborhood node is stored in these variables.

YJ,JY The Y coordinate difference for the same two nodes as XI above.

KANG The angle at which the terminal node lies from the current route node is measured from the x-axis and assigned to KANG.

IANG This angle is the direction of a neighborhood node from the route node.

IAK This angle is the difference between KANG and IANG.

RANG The range from the route node to the terminal node is stored in this variable.

RA This range is from the route node to the neighborhood node.

FORTRAN LISTING

```

PROGRAM SEARCH(INPLT=/80,OUTPUT=/137,TAPE5=INPUT,
1 TAPE6=OUTPUT,TAPE7,TAPE8,TAPE9)
COMMON/ICAT/ KMAT,ISTRIP,IDATA(15,15,10)
COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NFI,
1 SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250),
1 ISET(250),MSET(250),CERIOD(250,3)
COMMON/SENVEH/ LALT,FALT,SENALT,VEHALT,IFREE,GRID,
1 SWEA,SWAR,LTRS
COMMON/SRAD/ RANGE,RE,MDIM,RATE,NSITE,ISITE(10,3),SYSR(10)
INTEGER FALT,CERIOD,HICEN,GRID,SWEA,SWAR,SAVETP
INTEGER SENALT,VEHALT
DATA INT,KMAT,ISTRIP,GRID,RANGE/10,10,10,70,14.3/
DATA KCET,LWRIT,LDEBG,NLOW,NFI/0,1,1,0,0/

C
C *** KMAT IS SET UP FOR 10 ARRAYS WITHIN A STRIP OF DATA **
C *** ISTRIP IS SET UP FOR 10 STRIPS **
C
  NSITE = 3
  LWRIT = 3
  LDEBG = 1

C
C *** READ INPUT DATA **
C
  READ(5,900) ISTRIP,KMAT,SAVETP,LWRIT,LDEBG
  READ(5,901) INT,GRID,LTRS,SWEA,SWAR
  READ(5,902) SENALT,VEHALT,IRADUS,RANGE,RE,RATE,MDIM
  READ(5,903) INITIAL(2),INITIAL(1),INITIAL(3)
  READ(5,903) LAST(2),LAST(1),LAST(3)
  READ(5,904) NSITE
  IF(NSITE .GT. 10) GO TO 1200
100 DO 125 I=1,NSITE
  READ(5,903) ISITE(I,2),ISITE(I,1),ISITE(I,3)
  READ(5,905) SYSR(I)
125 SYSR(I) = SYSR(I)*1000.0/GRID

C
  WRITE(6,910)
  DO 1000 JK=1,ISTRIP
  JSTRIP = JK
  CALL INDATA

C
C *** GROUP DATA INTO ALTITUDE BANDS **
C *** INT IS THE BAND INTERVAL **
C *** JMAT IS THE MATRIX BEING SUBDIVIDED FOR ANALYSIS **
C
  DO 660 I=1,15
  DO 660 J=1,15
  DO 660 K=1,KMAT
660 IDATA(I,J,K)=(((IDATA(I,J,K)-1)/INT)*INT)+INT

C
C *** FIND THE LOCATION OF THE SENSORS IN THE TERRAIN DATA **
C

```

```

DO 700 I=1,NSITE
  ICOL = JK*15
  NX = ISITE(I,2)
  IF(NX .GT. ICCL) GO TO 700
  ICOL = (JK-1)*15
  IF(NX .LT. ICOL) GO TO 700
  NX = NX-(JK-1)*15
  NY = ISITE(I,1)
  NZ = (NY-1)/15
  NY = NY-NZ*15
  NZ = NZ+1
  ISITE(I,3) = IDATA(NY,NX,NZ)
700 CONTINUE
  IF (LWRIT .LE. 4) GO TO 675
  DO 501 K=1,KMAT
    WRITE(6,911)
    501 WRITE(6,912) ((IDATA(I,J,K),J=1,15),I=1,15)
    WRITE(6,910)
  C
  C *** MINALT FINDS MIN AND MAX ELEVATION IN EACH ARRAY **
  C *** HILOELV OVERSEE THE CLUSTERING OF ELEVATION BANDS **
  C
  675 DO 800 JJ=1,KMAT
    JMAT = JJ
    IC=1
    IK=1
    CALL MINALT(IC,IK)
    CALL HILOELV(IC,IK,1)
    IF(IC .EG. 225) GO TO 800
    CALL HILOELV(IK,IK,2)
  800 CCNTINUE
  1000 CCNTINUE
    WRITE(6,910)
    WRITE(6,915) ISTRIP,KMAT,SAVETP,LWRIT,LDEEG
    WRITE(6,916) INT,GRID,LTRS,SWEA,SLAR
    WRITE(6,917) SENALT,VEHALT,IRADUS,RANGE,RE,RATE,MDIM
    WRITE(6,918) INITIAL(2),INITIAL(1),INITIAL(3)
    WRITE(6,919) LAST(2),LAST(1),LAST(3)
    WRITE(6,913)
    DO 1100 I=1,NSITE
  1100 WRITE(6,920) ISITE(I,2),ISITE(I,1),ISITE(I,3),SYSR(I)
    CALL LINKAGE
    IF(SAVETP .GT. 0) CALL SAVE
    STOP
  1200 WRITE(6,914) NSITE
    NSITE = 10
    GO TO 100
  C
  900 FORMAT(5I5)
  901 FORMAT(2I5,10X,A2,2I4)
  902 FORMAT(3I5,3F10.3,I5)
  903 FORMAT(3I10)

```

```
904 FORMAT(I5)
905 FORMAT(F10.2)
910 FORMAT(1+1)
911 FORMAT(/10X,*ALTITUDE ARRAY*/ )
912 FORMAT(15(1X,I6))
913 FORMAT(20X,*SENSOR LOCATION*/24X,*X*,7X,*Y*,7X,*Z*,
1 7X,*SYS R*)
914 FORMAT(/////5X,*NUMBER OF SITES GREATER THAN 10 -*,16/
1 6X,*NSITE SET TO 10*)
915 FORMAT(//20X,*INPUT DATA*/20X,*ISTRIP KMAT SAVETP *,
1 *LWRIT LCEBG*/ 20X,5(I5,1X))
916 FORMAT(/20X,*INT GRID LTRS SWEA SWAR*/
1 20X,2(I5,1X),A2,2(1X,I5))
917 FORMAT(/20X,*SENALT VEHALT IRADUS RANGE RE*,10X,
1 *RATE MDIM*/20X,3(I5,1X),F8.3,1X,F10.2,1X,F8.3,1X,I6)
918 FORMAT(/20X,*INITIAL POINT ON ROUTE - X,Y,Z*/
1 20X,3(I6,2X))
919 FORMAT(/20X,*CESTINATION POINT FOR ROUTE - X,Y,Z*/
1 20X,3(I6,2X))
920 FORMAT(20X,3(I5,3X),F10.3)
END
```


SUBROUTINE HILOELV(IC,IK,ILO)

```

C
C *** THIS SUBROUTINE CONTROLS HIGH/LOW CLUSTERING **
C *** IC IS THE NUMBER OF MEMBERS IN LOWCEN **
C *** IK IS THE NUMBER OF MEMBERS IN HICEN **
C *** LOWCEN CONTAINS THE LOW ELEVATION CENTROIDS **
C *** HICEN CONTAINS THE HIGH ELEVATION CENTROIDS **
C *** NLOW IS THE NUMBER OF LOWCEN CENTROIDS **
C *** NHI IS THE NUMBER OF HICEN CENTROIDS **
C *** KCET IS CURRENT COUNT OF CLUSTER MEMBERSHIP **
C
      COMMON/ICAT/  KMAT,ISTRIP,IDATA(15,15,10)
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
1      SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LF
      COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250),
1      ISET(250),MSET(250),CEROID(250,3)
      COMMON/SENVEF/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
1      SWEA,SWNR,LTRS
      INTEGER HALT,CERCID,HICEN

C
      IF(ILO .EQ. 2) GO TO 20

C
C *** PROCESS LOWCEN **
C *** IF IC=1 ONLY ONE VALUE WAS FOUND FOR MEMBERSHIP **
C *** IF IC=225 THEN ALL THE ELEVATION VALUES ARE THE SAME **
C *** THE SAME LOGIC IS USED FOR IK **
C
      LF = 1
      IF(IC .EQ. 1) GO TO 500
      IF(IC .EQ. 225) GO TO 550
      CALL CLUST(IC)
      GO TO 610
500 IPOINT(1) = 1
      GO TO 600
550 IPOINT(1) = 113
600 CALL CALCEN(1)
610 CONTINUE

C
C *** STORE NEW MEMBERS **
C
      DO 625 L=1,KCET
        LOWCEN(NLOW+L,1) = CEROID(L,1)
        LOWCEN(NLOW+L,2) = CEROID(L,2)
625 LOWCEN(NLOW+L,3) = CEROID(L,3)
      NLOW = NLOW+KCET
      KCET = 0
      CC 650 L=1,250
        ISET(L) = 0
650 IPOINT(L) = 0
      RETURN

C
C *** PROCESS HICEN **
C

```

```

20  LH = 2
    DO 100 I=1,IK
100  ISET(I) = MSET(I)
     IF(IK .EQ. 1)   GO TO 700
     IF(IK .EQ. 225) GO TO 750
     CALL CLUST(IK)
     GO TO 810
700  IPOINT(1) = 1
     GO TO 800
750  IPOINT(1) = 113
800  CALL CALCEN(1)
810  CONTINUE
C
C *** STORE NEW MEMBERS **
    DO 825 L=1,KCET
      HICEN(NHI+L,1) = CEROID(L,1)
      HICEN(NHI+L,2) = CEROID(L,2)
825  HICEN(NHI+L,3) = CEROID(L,3)
      NHI = NHI+KCET
      KCET = 0
    DO 850 L=1,250
      ISET(L) = 0
850  IPOINT(L) = 0
      RETURN
      END

```

```
SUBROUTINE INDATA  
COMMON/IDAT/  KMAT,ISTRIP,IDATA(15,15,10)  
COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NFI,  
1  SMAX,LWRIT,LCEBG,JMAT,JSTRIP,LH  
INTEGER HALT
```

```
C  
C *** READ INPUT TERRAIN DATA **  
C
```

```
READ(8) LALT,HALT  
DO 600 IMAT=1,KMAT  
600 READ(8) ((IDATA(IRCW,ICOL,IMAT),IROW=1,15),ICOL=1,15)  
RETURN  
END
```

```

SUBROUTINE MINALT(IC,IK)
C
C *** THIS SUBROUTINE FINDS THE MIN AND MAX ELEVATION **
C *** BANDS IN EACH JMAT ARRAY OF IDATA. IVAL IS THE **
C *** ARRAY ELEMENT THAT IS BEING CHECKED FOR MIN/MAX **
C
COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NFI,
1  SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
COMMON/POINT/ INITIAL(3),LAST(3),IPCINT(250),
1  ISET(250),MSET(250),CEROID(250,3)
COMMON/IDAT/ KMAT,ISTRIP,IDATA(15,15,10)
INTEGER CEROIC,HICEN
C
DO 5 I=1,250
MSET(I) = 0
5 ISET(I) = 0
20 IFF = 1
IL = 15
JF = 1
JL = 15
600 MIN VAL = 999999
MAX VAL = -999999
C
C *** FOR IVAL **
C *** A POSITIVE VALUE INDICATES IVAL OUTSIDE CLUSTER **
C *** A ZERO VALUE - IVAL IN CLUSTER **
C *** A NEGATIVE VALUE INDICATES A NEW CLUSTER **
C
DO 800 I=IFF,IL
DO 800 J=JF,JL
IVAL=IDATA(I,J,JMAT)
IF(IVAL - MIN VAL) 700,750,625
625 IF(MAX VAL - IVAL) 650,660,800
C
C *** STORE INDICES FOR I AND J WITH MAXIMAL VALUE IN MSET **
C *** IK IS A COUNT OF THE VALUES FOUND **
C
650 IK = 0
MAX VAL = IVAL
660 IK = IK+1
MSET(IK) = I*100+J
GO TO 800
C
C *** STORE INDICES FOR I AND J WITH MINIMAL VALUE IN ISET **
C *** IC IS A COUNT OF THE VALUES FOUND **
C
700 IC=0
MIN VAL = IVAL
750 IC = IC+1
ISET(IC) = I*100+J
800 CONTINUE
RETURN
END

```

```

SUBROUTINE CLUST(IC)
COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NFI,
1  SMAX,LWRIT,LDERG,JMAT,JSTRIP,LH
COMMON/PCINT/ INITIAL(3),LAST(3),IPPOINT(250),
1  ISET(250),MSET(250),CEROID(250,3)
INTEGER CEROID,HICEN

C
C *** THIS SUBROUTINE FINDS THE MEMBERS OF EACH CLUSTER **
C *** IPOINT STORES THE INDEX OF ISET FOR THE CURRENT CLUSTER **
C *** I IS THE BEGINNING OF THE ISET CLUSTER **
C *** J IS THE CURRENT VALUE IN ISET BEING EVALUATED **
C *** FOR INCLUSION IN THE CLUSTER **
C
      I=1
      30 K=1
      IPOINT(1)=I
      35 J = I+1
      40 IVAL = ISET(J)-ISET(I)
      52 IF((IVAL.EG.1).OR.(IVAL.EG.99).OR.(IVAL.EG.100).OR.
      1  (IVAL.EG.101)) GO TO 60
C
C *** TRUE - INCREMENT I **
      IF(IVAL .GT. 101) GO TO 54
C
C *** TRUE - J IS PAST LAST ENTRY **
      IF(IVAL .LE. 0) GO TO 82
      J = J+1
      IF( J .GT. (I+16)) GO TO 70
      GO TO 40
      54 IF((I+1) .EG. J) GO TO 85
      I = I+1
      GO TO 35
C
C *** PLACE IVAL INTO CLUSTER USING ITS INDEX **
C
      60 DO 62 L=1,K
      62 IF(IPOINT(L) .EG. J) GO TO 64
      K = K+1
      IPOINT(K) = J
      64 J = J+1
      GO TO 40
C
C *** NO CHANGE IN K INDICATES THAT NO NEW MEMBERS EXIST **
      70 IF(K .EG. 1) GO TO 75
      I = I+1
      GO TO 35
C
C *** ISOLATED POINT ***
      75 CALL CALCEN(1)
      I = I+1
      IF(I .GT. IC) RETURN
      GO TO 30

```

```
82 IF((I+1) .LT. IC) GO TO 84
   DC 83 I=1,K
83 IF(IPCINT(L) .EQ. (J-1)) GO TO 90
   I = I+1
   IF(I .GT. IC) GO TO 90
   GO TO 35
84 I = I+1
   GO TO 35
85 CALL CALCEN(K)
   I = I+1
   GO TO 30
C
C *** END CLUSTER ***
C
90 CALL CALCEN(K)
   RETURN
   END
```

```

      SUBROUTINE CALCEN(K)
C
C *** DETERMINE THE CENTROID OF THE CLUSTER ***
C
      COMMON/ICAT/ KMAT,ISTRIP,IDATA(15,15,10)
      COMMON/LCENT/ LWCEN(250,3),HCEN(250,3),KCET,NLOW,NHI,
1    SMAX,LWRIT,LDERG,JMAT,JSTRIP,LH
      COMMON/POINT/ INITIAL(3),LAST(3),IPPOINT(250),
1    ISET(250),MSET(250),CERCID(250,3)
      COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
1    SWEA,SWNR,LTRS
      INTEGER CERCID,HCEN,HALT
C
C *** INUM IS THE ROW INDEX - Y COORD **
C *** JNUM IS THE COLUMN INDEX - X COORD **
C
      KDUM = 0
      JNUM = 0
      INUM = 0
      KCET = KCET+1
C
C *** CALCULATE THE MEAN VALUES **
C
      DO 100 L=1,K
        LL = IPPOINT(L)
        KDUM = ISET(LL)/100
        JNUM = (ISET(LL) - KDUM*100) + JNUM
100    INUM = KDUM + INUM
C
C *** THIS CALCULATION ADDS A HALF TO ALLOW FOR TRUNCATION **
C
      JNUM = (2*JNUM+K)/(2*K)
      INUM = (2*INUM+K)/(2*K)
      IF(JNUM .GT. 15) JNUM=15
      IF(INUM .GT. 15) INUM=15
C
C *** NEED TO STORE WHICH ARRAY IS BEING PROCESSED **
      IROW = (JMAT-1)*15+INUM
      ICOL = (JSTRIP-1)*15+JNUM
      CERCID(KCET,1) = IROW
      CERCID(KCET,2) = ICOL
      CERCID(KCET,3) = IDATA(INUM,JNUM,JMAT)
      IF(LWRIT .LE. 3) GO TO 10
      CALL WRITCL(K)
10    IF(LDERG .EQ. 1) RETURN
C
      WRITE(6,900) KDUM,JSTRIP,JMAT,INUM,JNUM,KCET,
1    CERCID(KCET,1),CERCID(KCET,2),CERCID(KCET,3),IROW,ICOL
900    FORMAT(10X,*KDUM JSTRIP JMAT INUM JNUM*,2X,
1    *KCET CERCID(1,1),(1,2),(1,3) IROW ICOL*/
2    10X,6(15,1X),5X,3(16,2X),2(15,1X))
      WRITE(6,901) NLOW,NHI,LALT,HALT,LH

```

```
501 FORMAT(10X,*NLOW  NHI  LALT  HALT  LF*/  
1      10X,5(15,1X))  
      RETURN  
      END
```


SUBROUTINE WRITCL(K)

```

C
C *** THIS SUBROUTINE WRITES RESULTS OF CLUSTERING **
C *** LH - 1 IS LOWCEN, 2 IS HICEN **
C
COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
1 SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
COMMON/PCINT/ INITIAL(3),LAST(3),IPOINT(250),
1 ISET(250),MSET(250),CERCID(250,3)
INTEGER CERCID,HICEN
DATA NEXT,NEXTL,NEXTH/1,1,1/
NEXT = NEXTL
IF(LH .EQ. 2) NEXT=NEXTH
WRITE (6,900)
900 FORMAT(///)
IF(LH .EQ. 1) WRITE(6,901)
IF(LH .EQ. 2) WRITE(6,902)
901 FORMAT(//10X,*LOW ELEVATION CLUSTER*//)
902 FORMAT(//10X,*HIGH ELEVATION CLUSTER*//)
WRITE (6,903) NEXT,K
WRITE (6,904) (IPOINT(I),I=1,K)
903 FORMAT(5X,*CLUSTER NUMBER *,I4/
1 5X,*TOTAL MEMBERS IN CLUSTER *,I3/)
904 FORMAT(5X,*PCINTERS TO CLUSTER MEMBER*/10(2X,I8))
N1 = IPOINT(1)
N2 = IPOINT(K)
WRITE (6,905) (ISET(I),I=N1,N2)
WRITE (6,906) NEXT,CERCID(KCET,2),CERCID(KCET,1),
1 CERCID(KCET,3)
905 FORMAT(//5X,*PACKED CLUSTER LOCATION ROW-COLUMN*/10(2X,I8))
906 FORMAT(// 5X,*CENTER OF CLUSTER NUMBER *,I4/
1 5X,*X-COORD*,I4,* Y-COORD*,I4,* Z-COORD*,I4///)
NEXT = NEXT+1
IF(LH .EQ. 1) NEXTL=NEXT
IF(LH .EQ. 2) NEXTH=NEXT
RETURN
END

```

SUBROUTINE LINKAGE

```

C
C *** LINKAGE ROUTINE **
C *** IPCINT HAS LIST OF NEIGHBORHOOD POINTS **
C *** NODE - NODE NUMBER OF POINT BEING EVALUATED **
C *** NLOW - NUMBER OF POINTS IN LOWCEN **
C *** NHI - NUMBER OF POINTS IN HICEN **
C *** LNEBR - POINTS IN NEIGHBORHOOD FOR LOWCEN **
C *** KNEBR - POINTS IN NEIGHBORHOOD FOR HICEN **
C
COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
1 SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
COMMON/POINT/ INITIAL(3),LAST(3),IPCINT(250)
COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
1 SWEA,SWNR,LTRS
COMMON/SRAD/ RANGE,RE,MDIM,RATE,NSITE,ISITE(10,3),SYSR(10)
COMMON/KINK/ LINK(250),LINKTO(1500,3),NBLKS,IC,
1 IRADUS,LNEBR,KNEBR
COMMON/DET/ DETLO(250),DETHI(250),FROM(250),TO(250,2)
COMMON/EDGE/ DIST(100,2),IRCW,JCCL,LSTR
DIMENSION MPCINT(125),SR(10,3),NLIST(250)
INTEGER HICEN,GRID,FROM,TO,SWEA,SWNR
INTEGER EAST1,EAST2
EQUIVALENCE (IPOINT(126),MPOINT(1))
DATA IRADUS/15/
DATA DETLO,DETHI/500*0/
DATA SMAX,RTCC/100.0,57.2957795131/
C
NBLKS = OLDB = 1
IFREE = KFIRST = KLAST = 0
LTOTAL = 0
C
C *** SORT LOWCEN AND HICEN **
C
CALL LHSCRT(KFIRST,KLAST)
C
C *** DEVELOP NETWORK **
C
CALL RADIAL
DO 10 I=1,250
FROM(I) = 0
TO(I,1) = 0
10 TO(I,2) = 0
C
C *** CONSTRUCT ROUTE **
C
15 IC = 1
NODE = KFIRST
NEWPT = NODE
C
C *** FIND NEIGHBORHOOD ABOUT A LOW POINT **
C

```

```

20 IROW = LOWCEN(NODE,1)
   JCOL = LOWCEN(NODE,2)
   LOWCEN(NODE,1) = -(1000000+IROW)
   LOWCEN(NODE,2) = -(1000000+JCOL)
   CALL NEIGHB(NODE)
   CALL DIFFER(NODE)

C
30 FROM(IC) = NEWPT
   IF(LWRIT .LE. 2) GO TO 35
   WRITE(6,921) NODE,JCOL,IROW,NEWPT,LPEN,IC
35 XI = LAST(2)-JCOL
   YJ = LAST(1)-IROW
   KANG = RTOD*(ATAN2(YJ,XI))
   RANG = SGRT(XI**2 + YJ**2)
   DO 50 I=1,NSITE
     XI = ISITE(I,2)-JCOL
     YJ = ISITE(I,1)-IROW
     SR(I,1) = SGRT(XI**2 + YJ**2)
     IF((XI .EQ. 0.0) .OR. (SR(I,1) .EQ. 0)) GO TO 50
     SR(I,2) = RTOD*(ATAN2(YJ,XI))
     SR(I,3) = ABS(RTOD*(ATAN2(SYSR(I),SR(I,1))))
50 CONTINUE

C
C ***      FIND MIN PENALTY VALUE      **
C *** ANGLE HEADING IS MEASURED FROM X-AXIS **
C *** IAK ANGLE IS MEASURED FROM HEADING **
C *** THREE WEIGHTING SCHEMES **
C *** HEADING, RADAR AVOIDANCE, TERMINAL **
C
   LPEN = 1000000
   LA = LINK(IC)
   LB = LINK(IC+1)-1
   IF(LB .LE. 0) LB=IFREE
   DO 200 LL=LA,LB
     NJ = LINKTO(LL,1)
     IF(NJ .LT. 0) GO TO 120
     IX = LOWCEN(NJ,2)
     JY = LOWCEN(NJ,1)
     GO TO 125
120 IX = HICEN(-NJ,2)
     JY = HICEN(-NJ,1)
125 XI = IX-JCOL
     YJ = JY-IROW
     RA = SGRT(XI**2 + YJ**2)
     IANG = RTOD*(ATAN2(YJ,XI))
     IAK = IANG-KANG
     IF(IAK .GT. 180) IAK=360-IAK
     IF(IAK .LT. -180) IAK=360+IAK

C
C *** HEADING WEIGHTING **
C
   NWEIG = (IABS(IAK))/90+1

```

```

      IF(RANG .GT. RANGE) GO TO 130
C
C *** TERMINAL WEIGHTING **
C
      NWEIG = 2*(IABS(IAK)/45)+1
      IF(RA .GT. RANG) NWEIG=100*NWEIG
      GO TO 150
C
C *** RADAR AVOIDANCE WEIGHTING **
C
130 IF(SYSR(1) .LE. 0.0) GO TO 150
      DO 135 I=1, NSITE
      ANG = IANG
      ANG = ABS(SR(I,2)-ANG)
      IF(ANG .GT. SR(I,3)) GO TO 135
      NWEIG = 2
      IF(RA .GT. (SR(I,1)-SYSR(I))) NWEIG=10
      GO TO 150
135 CONTINUE
150 NPEN = NWEIG*LINKTO(LL,2)+NWEIG
      LINKTO(LL,3) = NPEN
C
      IF(LWRIT .LE. 2) GO TO 175
      WRITE(6,920) NODE,NJ,LA,LB,IC,IFREE,RANGE,RANG,RA
      WRITE(6,924) IAK,IANG,KANG,NWEIG,LPEN,NPEN,XI,YJ
175 IF(NPEN .GE. LPEN) GO TO 200
      LPEN = NPEN
      NEWPT = LINKTO(LL,1)
200 CONTINUE
C
      IF(LWRIT .GT. 2) WRITE(6,921) NODE,JCOL,IROW,NEWPT,LPEN,IC
      IF(NEWPT .EQ. KLAST) GO TO 475
      NODE = NEWPT
      TC(IC,1) = NEWPT
      TC(IC,2) = LPEN
      IC = IC+1
      LTOTAL = LTOTAL+LPEN
      IF(IC .GE. 1950) CALL RITE
      IF(IFREE .GE. 1800) CALL RITE
      IF(NODE .LT. 0) GO TO 400
      GO TO 20
C
C *** FIND NEIGHBORHOOD ABOUT A HIGH PCINT **
C
400 NODE = -NEWPT
      IROW = HICEN(NODE,1)
      JCOL = HICEN(NODE,2)
      HICEN(NODE,1) = -(1000000+IROW)
      HICEN(NODE,2) = -(1000000+JCOL)
      CALL NEIGHB(NODE)
      CALL DIFFER(NODE)
      GO TO 30

```

```

450 IF(IFLAG .EQ. -1) GO TO 475
    IFLAG = -1
    IRADUS = 2*IRADUS
    GO TO 15
475 TO(IC,1) = NEWPT
    TO(IC,2) = LPEN
C
C *** CHECK FOR DATA BLOCKS WRITTEN TO WORKING STORAGE **
C
    IF(NBLKS .GT. 1) GO TO 700
C
C *** REMOVE LARGE NEGATIVE VALUE FROM ROUTE NODES **
C
480 DO 500 I=1,IC
    NN = FROM(I)
    IF(NN .LT. 0) GO TO 485
    LOWCEN(NN,1) = -(LOWCEN(NN,1)+1000000)
    LOWCEN(NN,2) = -(LOWCEN(NN,2)+1000000)
    GO TO 500
485 NN = -NN
    HICEN(NN,1) = -(HICEN(NN,1) +1000000)
    HICEN(NN,2) = -(HICEN(NN,2) +1000000)
500 CONTINUE
C
C *** WRITE NODE POINTS OF THE ROUTE **
C
    LL = 0
    WRITE(6,910)
    DO 650 I=1,IC
    LL = LL+1
    NOD1 = FROM(I)
    NOD2 = TO(I,1)
    IF(NOD1 .LT. 0) GO TO 550
    NORTH1 = GRID*LOWCEN(NOD1,1)+SWNR
    EAST1 = GRID*LOWCEN(NOD1,2)+SWEA
    IF(NOD2 .LT. 0) GO TO 575
525 NORTH2 = GRID*LOWCEN(NOD2,1)+SWNR
    EAST2 = GRID*LOWCEN(NOD2,2)+SWEA
    GO TO 600
550 NOD1 = -NOD1
    NORTH1 = GRID*HICEN(NOD1,1)+SWNR
    EAST1 = GRID*HICEN(NOD1,2)+SWEA
    IF(NOD2 .GT. 0) GO TO 525
575 NOD2 = -NOD2
    NORTH2 = GRID*HICEN(NOD2,1)+SWNR
    EAST2 = GRID*HICEN(NOD2,2)+SWEA
600 WRITE(6,911) FROM(I),EAST1,NORTH1,TO(I,1),
1      TO(I,2),EAST2,NORTH2
    IF(LL .LE. 29) GO TO 650
    WRITE(6,910)
    LL = 0
650 CONTINUE

```

```

WRITE(6,512) LTRS,SWEA,SWNR,LTOTAL
CALL WRLINK
ICK = IC-1
LA = 0
K = 1
DO 800 I=1,ICK
IF(K .GE. IC) GO TO 850
LA = LA+1
NJ = FROM(K)
NN = TC(K,1)
NLIST(LA) = NJ
IF(NJ .LT. 0) GO TO 670
JCOL = LCWCEN(NJ,2)
IROW = LCWCEN(NJ,1)
GO TO 675
670 JCOL = HICEN(-NJ,2)
IROW = HICEN(-NJ,1)
675 IF(NN .LT. 0) GO TO 680
IX = LCWCEN(NN,2)
JY = LCWCEN(NN,1)
GO TO 685
680 IX = HICEN(-NN,2)
JY = HICEN(-NN,1)
685 XI = IX-JCOL
YJ = JY-IROW
DISA = SGRT(XI**2 + YJ**2)
K = K+1
LL = K
DO 800 J=LL,IC
NJ = TC(J,1)
IF(NJ .LT. 0) GO TO 690
IX = LCWCEN(NJ,2)
JY = LCWCEN(NJ,1)
GO TO 695
690 IX = HICEN(-NJ,2)
JY = HICEN(-NJ,1)
695 XI = IX-JCOL
YJ = JY-IROW
DISB = SQRT(XI**2 + YJ**2)
IF(DISB .GT. DISA) GO TO 800
K = J+1
DISA = DISB
800 CONTINUE
I = ICK+1
LA = LA+1
NLIST(LA) = FROM(I)
850 CONTINUE
NLIST(LA+1) = TO(IC,1)
WRITE(6,515)
DO 875 J=1,LA
875 WRITE(6,516) NLIST(J),NLIST(J+1)

```

C

```

      IF(NBLKS .LT. CLCE) GO TO 710
      RETURN
700 CALL RITE
      OLDB = NBLKS-1
      REWIND 9
710 READ(9) NBLKS,IFREE,IC
      READ(9) (FROM(I),I=1,IC)
      READ(9) ((TO(I,J),J=1,2),I=1,IC)
      READ(9) (LINK(I),I=1,IC)
      READ(9) ((LINKTO(I,J),J=1,3),I=1,IFREE)
      GO TO 480

```

C

```

910 FORMAT(1H1////////30X,*TABLE      NODE LINKAGE FOR ROUTE*//
      1 19X,*FROM*,4X,*EASTING*,2X,*NORTHING*,
      2 6X,*TO*,4X,*PENALTY*,3X,*EASTING*,2X,*NORTHING*//)
911 FORMAT(18X,I5,2X,2(I9,1X),2X,I5,2X,3(I9,1X))
912 FORMAT( //19X,*SOUTHWEST CORNER *,A2,2I4//
      1 110X,*TOTAL PENALTY*/110X,*RUNNING TOTAL*/110X,I12)
915 FORMAT(1H1////////30X,*TABLE      MODIFIED ROUTE*//
      1 37X,*FROM*,5X,*TO*//)
916 FORMAT(36X,I5,2X,I5)
920 FORMAT(/6X,*NODE NJ   LA  LB  IC  IFREE RANGE*,
      1 6X,*RANG   RA*/5X,6(I4,1X),3(F8.3,1X))
921 FORMAT(10X,*NODE X-CRD Y-CRD*/10X,3(I4,1X)/10X,*NEWPT*,
      1      2X,*LPEN      IC*/10X,I4,1X,I10,1X,I4)
924 FORMAT( 8X,*IAK IANG  KANG  NWEIG      LPEN*,
      1 7X,*NPEN*, 5X,*XI*,10X,*YJ*/
      1 5X,I5,1X,I5,1X,I5,1X,I5,1X,I10,1X,I10,2(F10.4,1X))
      END

```

SUBROUTINE LHSORT(KFIRST,KLAST)

```

C
C *** THIS SUBROUTINE SORTS LOWCEN AND HICEN **
C *** IN ASCENDING ORDER BY ROWS **
C
COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NFI,
1  SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250)
INTEGER HICEN
C
NLOW = NLOW+1
LOWCEN(NLOW,1) = INITIAL(1)
LOWCEN(NLOW,2) = -INITIAL(2)*LAST(2)
LOWCEN(NLOW,3) = INITIAL(3)
NLOW = NLOW+1
LOWCEN(NLOW,1) = LAST(1)
LOWCEN(NLOW,2) = -LAST(2)
LOWCEN(NLOW,3) = LAST(3)
C
C *** LOWCEN **
C
KK = NLOW-1
DO 10 J=1,KK
JJ = J+1
DO 10 I=JJ,NLOW
IF(LOWCEN(J,1) .LE. LOWCEN(I,1)) GO TO 10
IS1 = LOWCEN(J,1)
IS2 = LOWCEN(J,2)
IS3 = LOWCEN(J,3)
LOWCEN(J,1) = LOWCEN(I,1)
LOWCEN(J,2) = LOWCEN(I,2)
LOWCEN(J,3) = LOWCEN(I,3)
LOWCEN(I,1) = IS1
LOWCEN(I,2) = IS2
LOWCEN(I,3) = IS3
10 CONTINUE
C
IS2 = -INITIAL(2)*LAST(2)
DO 15 I=1,NLOW
IF(LOWCEN(I,2) .GT. 0) GO TO 15
IF(LOWCEN(I,2) .EQ. IS2) KFIRST=I
IF(LOWCEN(I,2) .EQ. -LAST(2)) KLAST=I
15 CONTINUE
WRITE(6,907) INITIAL(2),LAST(2),IS2,LOWCEN(KFIRST,2),
1 LOWCEN(KLAST,2),KFIRST,KLAST
907 FORMAT(/ 2X,*INITIAL*,2X,*LAST*,4X,*IS2*,6X,*LOWCEN-1*,
1 2X,*LOWCEN-L*,2X,*KFIRST*,3X,*KLAST*/2X,7(16,2X))
LOWCEN(KFIRST,2) = INITIAL(2)
LOWCEN(KLAST,2) = LAST(2)
WRITE(6,906)
WRITE(6,900)
KL = 0

```



```

DO 20 I=1,NLCW,10
KK = I-1+10
IF(KK .GT. NLOW) KK=NLOW
KL = KL+1
WRITE(6,901) (LOWCEN(J,2),J=I,KK)
WRITE(6,902) (LOWCEN(J,1),J=I,KK)
WRITE(6,903) (LOWCEN(J,3),J=I,KK)
IF(KL .LE. 7) GO TO 20
WRITE(6,906)
WRITE(6,900)
KL = 0
20 CONTINUE
WRITE(6,904) NLOW
C
C *** HICEN **
C
KK = NHI-1
DO 30 J=1,KK
JJ = J+1
DO 30 I=JJ,NHI
IF(HICEN(J,1) .LE. HICEN(I,1)) GO TO 30
IS1 = HICEN(J,1)
IS2 = HICEN(J,2)
IS3 = HICEN(J,3)
HICEN(J,1) = HICEN(I,1)
HICEN(J,2) = HICEN(I,2)
HICEN(J,3) = HICEN(I,3)
HICEN(I,1) = IS1
HICEN(I,2) = IS2
HICEN(I,3) = IS3
30 CONTINUE
C
WRITE(6,906)
WRITE(6,905)
KL = 0
DO 40 I=1,NHI,10
KK = I-1+10
IF(KK .GT. NHI) KK=NHI
KL = KL+1
WRITE(6,901) (HICEN(J,2),J=I,KK)
WRITE(6,902) (HICEN(J,1),J=I,KK)
WRITE(6,903) (HICEN(J,3),J=I,KK)
IF(KL .LE. 7) GO TO 40
WRITE(6,906)
WRITE(6,905)
KL = 0
40 CONTINUE
WRITE(6,904) NHI
WRITE(6,906)
C
900 FORMAT(////////40X,*TABLE          LOW ELEVATION NODE POINTS*//)
901 FORMAT(12X,*X-COORDINATE *,10I7)

```

```
902 FORMAT(18X,*Y-COORDINATE *,10I7)
903 FORMAT(18X,*Z-COORDINATE *,10I7/)
904 FORMAT(//18X,*NUMBER OF NODES *,I5)
905 FORMAT(////////40X,*TABLE      HIGH ELEVATION NODE POINTS*//)
906 FORMAT(1H1)
      RETURN
      END
```

```

SUBROUTINE NEIGHB(NODE)
C
C *** IROW IS ROW INDEX (Y-COORD) BEING EVALUATED **
C *** JCOL IS COLUMN INDEX (X-COORD) **
C *** NODE LOCATION CURRENTLY BEING PROCESSED **
C
COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
1 SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250)
COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
1 SWEA,SWNR,LTRS
COMMON/KINK/ LINK(250),LINKTO(1500,3),NBLKS,IC,
1 IRADUS,LNEBR,KNEBR
COMMON/EDGE/ DIST(100,2),IROW,JCOL,LSTR
DIMENSION MPOINT(125)
INTEGER HICEN
EQUIVALENCE (IPOINT(125),MPOINT(1))
C
C IRAD = IRADUS
10 LA = IROW-IRAD
IF(LA .LE. 0) LA=1
LB = IROW+IRAD
C
C *** IBEG IS THE INDEX VALUE WHERE LA = ROW NUMBER **
C *** IEND IS THE INDEX VALUE WHERE LB+1 = ROW # **
C *** IPOINT HAS INDEX VALUE OF LOWCEN FOR NEIGHBORHOOD **
C *** THIS RESTRICTS THE SEARCH TO ONLY THOSE ROWS **
C *** THAT ARE NEAR THE "NODE" **
C
DO 100 I=1,NLOW
NROW = LOWCEN(I,1)
IF(NROW .LT. LA) GO TO 100
IBEG = I
GO TO 101
100 CCINUE
101 DO 102 I=IBEG,NLOW
NROW = LOWCEN(I,1)
IF(NROW .LT. LB) GO TO 102
IEND = I
GO TO 103
102 CCINUE
C
C *** FIND THE NEIGHBORHOOD OF LOW ELEVATION POINTS **
C
103 LNEBR = 0
DO 104 I=IBEG,IEND
IF(LOWCEN(I,1) .LT. -1000000) GO TO 104
LDIFF = IABS(LOWCEN(I,1)-IROW)
IF(LDIFF .GT. IRAD) GO TO 104
LDIFF = IABS(LOWCEN(I,2)-JCOL)
IF(LDIFF .GT. IRAD) GO TO 104
LNEBR = LNEBR+1

```

```

      IF(LNEBR .EQ. 100) GO TO 400
      IPOINT(LNEBR) = I
104  CONTINUE
      IF(LNEBR .EQ. 0)   GO TO 300
125  IFLAG = 0
      DO 200 I=1,NFI
      NROW = HICEN(I,1)
      IF(NROW .LT. LA)   GO TO 200
      IBEG = I
      GO TO 201
200  CONTINUE
201  DO 202 I=IBEG,NHI
      NROW = HICEN(I,1)
      IF(NROW .LT. LB)   GO TO 202
      IEND = I
      GO TO 203
202  CCNTINUE
C
C *** FIND THE NEIGHBORHOOD OF HIGH ELEVATION POINTS **
C
203  KNEBR = 0
      DO 204 I=IBEG,IEND
      IF(HICEN(I,1) .LT.-1000000) GO TO 204
      LDIFF = IABS (HICEN(I,1)-IROW)
      IF(LDIFF .GT. IRAD) GO TO 204
      LDIFF = IABS (HICEN(I,2)-JCOL)
      IF(LDIFF .GT. IRAD) GO TO 204
      KNEBR = KNEBR+1
      IF(KNEBR .GT. 100) GO TO 500
      MPOINT(KNEBR) = I
204  CONTINUE
      IF(LWRIT .LE. 2) RETURN
      WRITE(6,500) NODE,JCOL,IROW
      DO 275 N1=1,LNEBR
      N2 = IPOINT(N1)
275  WRITE(6,901) N1,N2,LOWCEN(N2,2),LOWCEN(N2,1),LOWCEN(N2,3)
      WRITE(6,902)
      DO 285 N1=1,KNEBR
      N2 = MPOINT(N1)
285  WRITE(6,901) N1,N2,HICEN(N2,2),HICEN(N2,1),HICEN(N2,3)
C
900  FORMAT(/EX,* PRIMARY NODE *,I4,I5,*,X-COORD *,
1  I5,*,Y-COORD*/10X,*LOW POINTS*)
901  FORMAT(10X,*NEIGHB - *,I3,* NODE *,I3,*,*,I5,
1  *,X-COORD *,I5,*,Y-COORD*,I5,*,Z-COORD*)
902  FORMAT(10X,*HIGH POINTS*)
      RETURN
C
C *** THIS ENSURES THAT AT LEAST ONE POINT BUT NOT MORE **
C *** THAN 100 POINTS ARE FOUND **
C
300  IRAD = 2*IRAC

```

AD-A091 793

ARMY MISSILE COMMAND REDSTONE ARSENAL AL PLANS ANAL--ETC F/G 15/3
A HEURISTIC ROUTE SELECTION MODEL FOR LOW LEVEL AIRCRAFT FLIGHT--ETC(U)
MAY 80 M J DORSETT

UNCLASSIFIED ORSMT/D-A0-5-TR

SRTE-AD-F950 080

MI

3-3

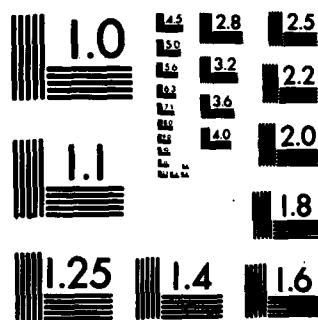
END

DATE

FORMED

1-89

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
      IF(IRAD .GT. 999999) RETURN  
      GO TO 10  
400  IRAD = IRAD/2  
      IF(IRAD .EQ. 0) GO TO 450  
      GO TO 10  
450  LNEBR = 100  
      GO TO 125  
500  IF(IFLAG .EQ. 1) GO TO 600  
      IRAD = IRAD/2  
      IFLAG = 1  
      GO TO 203  
600  KNEBR = 100  
      RETURN  
      END
```

SUBROUTINE DIFFER(NODE)

```

C
C *** THIS SUBROUTINE FINDS RANGE OF HEIGHT AND DISTANCE **
C *** DIST(I,1) = THE PLANAR DIST TO POINT FOR LOWCEN **
C *** CIST(I,2) = THE PLANAR DIST TO POINT FOR HICEN **
C *** DMIN = MIN DIST BETWEEN NODE AND ADJACENT POINTS **
C *** DMAX = MAX DIST BETWEEN NODE AND ADJACENT POINTS **
C *** KZMIN = MIN ELEVATION BETWEEN NODE AND ADJ PTS **
C *** KZMAX = MAX ELEVATION BETWEEN NODE AND ACJ PTS **
C
COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
1 SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250)
COMMON/SENVEP/ LALT,HALT,SENALT,VEFALT,IFREE,GRID,
1 SWEA,SWNR,LTRS
COMMON/KINK/ LINK(250),LINKTO(1500,3),NELKS,IC,
1 IRADLS,LNEBR,KNEBR
COMMON/DET/ DETLO(250),DETHI(250),FROM(250),TO(250,2)
COMMON/EDGE/ DIST(100,2),IRCW,JCCL,LSTR
DIMENSION MPOINT(125)
INTEGER HICEN
EQUIVALENCE (IPOINT(126),MPOINT(1))
DATA RTCC,LSTR/57.2957795131,1/
C
C *** INITIALIZE VARIABLES **
C
DO 10 I=1,100
CIST(I,1) = 0.0
10 DIST(I,2) = 0.0
DMIN = 1000000
DMAX = -1000000
KZMIN = 1000000
KZMAX = -1000000
C
C *** PROCESS LOWCEN
C
DO 130 I=1,LNEBR
J = IPOINT(I)
YJ = LOWCEN(J,1)-IRON
XI = LOWCEN(J,2)-JCOL
KZI = LOWCEN(J,3)
IF(KZI .GE. KZMIN) GO TO 15
KZMIN = KZI
15 IF(KZI .LE. KZMAX) GO TO 20
KZMAX = KZI
20 CONTINUE
DIST(I,1) = SQRT(XI**2+YJ**2)
IF(DIST(I,1) .GE. DMIN) GO TO 120
DMIN = DIST(I,1)
120 IF(DIST(I,1) .LE. DMAX) GO TO 130
DMAX = DIST(I,1)
130 CCNTINUE

```



```

C
C *** PROCESS HICEN **
C
      CO 150 I=1,KNEBR
      J  = MPOINT(I)
      YJ = HICEN(J,1)-IROW
      XI = HICEN(J,2)-JCOL
      KZI = HICEN(J,3)
      IF(KZI .GE. KZMIN) GO TO 35
      KZMIN = KZI
      GO TO 45
35  IF(KZI .LE. KZMAX) GO TO 45
      KZMAX = KZI
45  CONTINUE
      DIST(I,2) = SQRT(XI**2+YJ**2)
      IF(DIST(I,2) .GE. DMIN) GO TO 140
      DMIN = DIST(I,2)
      GO TO 150
140 IF(DIST(I,2) .LE. DMAX) GO TO 150
      DMAX = DIST(I,2)
150 CONTINUE
      IF(LWRIT .LE. 2) GO TO 75
      WRITE(6,900) NODE,JCOL,IROW,LNEBR
      DO 50 LA=1,LNEBR,10
      LB = LA-1+10
      IF(LB .GT. LNEBR) LB=LNEBR
50  WRITE(6,901) (DIST(I,1),I=LA,LB)
      WRITE(6,900) NODE,JCOL,IROW,KNEBR
      DO 60 LA=1,KNEBR,10
      LB = LA-1+10
      IF(LB .GT. KNEBR) LB=KNEBR
60  WRITE(6,902) (DIST(I,2),I=LA,LB)
C
C *** SORT IN INCREASING ORDER **
C
75  IF(LNEBR .EQ. 1) GO TO 85
      KK = LNEBR-1
      DO 250 J=1,KK
      JJ = J+1
      DO 250 I=JJ,LNEBR
      IF(DIST(J,1) .LE. DIST(I,1)) GO TO 250
      SA1 = DIST(J,1)
      JSA = IPOINT(J)
      DIST(J,1) = DIST(I,1)
      IPOINT(J) = IPOINT(I)
      DIST(I,1) = SA1
      IPOINT(I) = JSA
250 CONTINUE
85  IF(KNEBR .EQ. 1) GO TO 300
      KK = KNEBR-1
      DO 275 J=1,KK
      JJ = J+1

```

```

DO 275 I=JJ,KNEBR
  IF(DIST(J,2) .LE. DIST(I,2)) GO TO 275
  SA1 = DIST(J,2)
  JSA = MPOINT(J)
  DIST(J,2) = DIST(I,2)
  MPOINT(J) = MPOINT(I)
  DIST(I,2) = SA1
  MPOINT(I) = JSA
275 CONTINUE
  IF(LWRIT .LE. 2) GO TO 300
  WRITE(6,903) DMIN,DMAX,KZMIN,KZMAX
  WRITE(6,900) NODE,JCOL,IROW,LNEBR
  DO 90 LA=1,LNEBR,10
    LB = LA-1+10
    IF(LB .GT. LNEBR) LB=LNEBR
  90 WRITE(6,901) (DIST(I,1),I=LA,LB)
    WRITE(6,900) NCDE,JCOL,IROW,KNEBR
    DO 95 LA=1,KNEBR,10
      LB = LA-1+10
      IF(LB .GT. KNEBR) LB=KNEBR
  95 WRITE(6,902) (DIST(I,2),I=LA,LB)
C
C *** CALCULATE PENALTY VALUE FOR POINTS **
C
300 DRANG = DMAX-DMIN
  IF(DRANG .GT. 0.0) DRANG=1.0/DRANG
  ZRANG = KZMAX-KZMIN+1
  IF(ZRANG .GT. 0.0) ZRANG=1.0/ZRANG
  DO 320 I=1,LNEBR
    IFREE = IFREE+1
    IJ = IPOINT(I)
    LINKTO(IFREE,1) = IJ
    XYZ = LOWCEN(IJ,3)-KZMIN
    XYZ = DETLC(IJ)+XYZ*ZRANG
  320 LINKTO(IFREE,2) = 100.0*(XYZ+1-(DIST(I,1)-DMIN)*DRANG)
    DO 325 I=1,KNEBR
      IFREE = IFREE+1
      IJ = MPOINT(I)
      LINKTO(IFREE,1) = -IJ
      XYZ = HICEN(IJ,3)-KZMIN
      XYZ = DETHI(IJ)+XYZ*ZRANG
  325 LINKTO(IFREE,2) = 100.0*(XYZ+1-(DIST(I,2)-DMIN)*DRANG)
    LINK(IC) = LSTR
    LSTR = IFREE+1
C
900 FORMAT(/ 5X,*FROM DIFFER* / 5X,*NODE *,I4,I5,*,X-COORD *,
1 I5,*,Y-COORD *,I5,*, LINKS*)
901 FORMAT( 5X,*DISTANCE LOW *,10(1X,F10.3))
902 FORMAT( 5X,*DISTANCE HIGH *,10(1X,F10.3)/)
903 FORMAT(11X,*CMIN*,8X,*DMAX KZMIN KZMAX*/
1 5X,2(F10.4,2X),I4,2X,I4)
  RETURN
END

```

SUBROUTINE RITE

```

C
C *** THIS SUBROUTINE SAVES ARRAYS IN WORKING STORAGE **
C
COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
1 SWEA,SWNR,LTPS
COMMON/KINK/ LINK(250),LINKTO(1500,3),NBLKS,IC,
1 IRADUS,LNEBR,KNEBR
COMMON/DET/ DETLO(250),DETHI(250),FROM(250),TO(250,2)
COMMON/EDGE/ DIST(100,2),IRCW,JCCL,LSTR
INTEGER FROM,TC
C *** BINARY UNFORMATTED TAPE **
WRITE(9) NBLKS,IFREE,IC
WRITE(9) (FROM(I),I=1,IC)
WRITE(9) ((TC(I,J),J=1,2),I=1,IC)
WRITE(9) (LINK(I),I=1,IC)
WRITE(9) ((LINKTO(I,J),J=1,3),I=1,IFREE)
IFREE = IC = LSTR = 1
NBLKS = NBLKS+1
RETURN
END

```

SUBROUTINE WRLINK

```

C
C *** THIS SUB* WRITES THE LINKAGE THAT'S BEEN DEVELOPED **
C
COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
1  SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250)
COMMON/SENVEH/ LALT,FALT,SENALT,VEH-ALT,IFREE,GRID,
1  SWEA,SWNR,LTRS
COMMON/KINK/ LINK(250),LINKTO(1500,3),NELKS,IC,
1  IRADUS,LNEBR,KNEBR
COMMON/DET/ DETLC(250),DETHI(250),FROM(250),TO(250,2)
INTEGER HICEN,FROM,TO
WRITE(6,900)
900 FORMAT(1F1 /10X,*NODE LINKAGE OUTPUT*)
WRITE(6,901) IFREE,NELKS,NLOW,IRADUS
901 FORMAT(10X,*IFREE NELKS      NLOW  IRADUS*/
1  10X,4(I6,1X))
NM = IFREE+1
DC 15 NA=1,NM,10
NB = NA-1+10
15 WRITE(6,902) (LINKTO(I,1),I=NA,NB),(LINKTO(I,2),I=NA,NB),
1  (LINKTO(I,3),I=NA,NB)
902 FORMAT(10X,*LINKTO(I,1)  *,10(2X,I6)/
1  10X,*LINKTO(I,2)  *,10(2X,I6)/
2  10X,*LINKTO(I,3)  *,10(2X,I6)/)
WRITE(6,903)
903 FORMAT(1F1)
WRITE(6,904)
DO 10 J=1,IC,10
JJ = J-1+10
IF(JJ .GT. IC) JJ=IC
10 WRITE(6,905) (LINK(I),I=J,JJ)
904 FORMAT(/10X,*LINKAGE POINTERS*/)
905 FORMAT(10X,10(I6,2X))
KC = 0
DC 20 NJ=1,IC
IF(KC .EG. 0) WRITE(6,906)
KC = KC+1
NN = FROM(NJ)
J = LINK(NJ)
JJ = LINK(NJ+1)-1
IF(JJ .LT. 0) JJ=IFREE
JJJ= JJ-J+1
WRITE(6,907) NN,JJJ
IF(NN .GT. 0) WRITE(6,908) LOWCEN(NN,2),
1  LOWCEN(NN,1),LOWCEN(NN,3)
IF(NN .LT. 0) WRITE(6,908) HICEN(-NN,2),
1  HICEN(-NN,1),HICEN(-NN,3)
WRITE(6,909) (LINKTO(I,1),I=J,JJ)
WRITE(6,910) (LINKTO(I,2),I=J,JJ)
WRITE(6,911) (LINKTO(I,3),I=J,JJ)

```

```
IF(KC .LE. 5) GO TO 20
```

```
KC = 0
```

```
20 CONTINUE
```

C

```
906 FORMAT(1F1/////////34X,*NODE LINKAGE*)
```

```
907 FORMAT(/20X,*NODE NO.*,I5,* TOTAL LINKS *,I4)
```

```
908 FORMAT(20X,*X,Y,Z COORDINATE *,I4,1F, ,1X,I4,1F, ,1X,I4)
```

```
909 FORMAT(20X,*LINKED TO *,10I7)
```

```
910 FORMAT(20X,*EXPOSURE *,10I7)
```

```
911 FORMAT(20X,*WEIGHTED *,10I7)
```

```
RETURN
```

```
END
```

SUBROUTINE SAVE

```

C
C *** THIS ROUTINE IS USED TO WRITE VALUES OUT FOR PLOTTING **
C
COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
1 SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
COMMON/SENVEP/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
1 SWEA,SWNR,LTRS
COMMON/KINK/ LINK(250),LINKTO(1500,3),NBLKS,IC,
1 IRADUS,LNEBR,KNEBR
COMMON/DET/ DETLO(250),DETHI(250),FROM(250),TO(250,2)
INTEGER FICEN,FROM,TO
C
WRITE(7,900) NLOW,NHI,IC,IFREE
WRITE(7,901) ((LOWCEN(I,J),J=1,3),I=1,NLOW)
WRITE(7,901) ((HICEN(I,J),J=1,3),I=1,NHI)
WRITE(7,902) (DETLO(I),I=1,NLOW)
WRITE(7,902) (DETHI(I),I=1,NHI)
WRITE(7,901) (FROM(I),I=1,IC)
WRITE(7,901) ((TO(I,J),J=1,2),I=1,IC)
WRITE(7,901) (LINK(I),I=1,IC)
WRITE(7,901) ((LINKTO(I,J),J=1,3),I=1,IFREE)
900 FORMAT(4I10)
901 FORMAT(10(I9,1X))
902 FORMAT(10F10.3)
RETURN
END

```

SUBROUTINE RADIAL

```

C
C *** THIS ROUTINE CALCULATES THE LINE OF SIGHT (LOS) **
C *** BETWEEN NODE POINT AND SENSORS. LOS IS THE **
C *** INTERVISIBILITY BETWEEN PTS. ONCE ANY TERRAIN **
C *** MASKING POINT IS FOUND PROCESSING OF THAT NODE- **
C *** SENSOR COMBINATION IS FINISHED. L**
C
COMMON/ICAT/ KMAT,ISTRIP,IDATA(15,15,10)
COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NFI,
1 SPAX,LWRIT,LDEEG,JMAT,JSTRIP,LF
COMMON/PCINT/ INITIAL(3),LAST(3),IPCONT(250)
COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
1 SWEA,SWNR,LTRS
COMMON/SRAD/ RANGE,RE,MDIM,RATE,NSITE,ISITE(10,3),SYSR(10)
COMMON/DET/ DETLC(250),DETHI(250),DISLC(250),
1 DISHI(250),XX(250)
DIMENSION IFINISH(250)
INTEGER SENALT,VEHALT,HICEN,EAST,WEST,SOUTH,GRID
LOGICAL ZCURVE,ZNORTH,ZSOUTH
EQUIVALENCE (RMAX,DIS)
DATA RE,SRTWH,RATE/P490200.0,0.7071068,1.0/
DATA SENALT,VEHALT,MDIM/3,10,15/

C
C *** INITIALIZE **
C
REWIND 8
ZCURVE = RE.GT.0.0
ZGRID = GRID
RE = RE/ZGRID
DZ = 0.0
C *** AREA LIMITS **
NORTH = KMAT+MDIM
SOUTH = 1
C
DO 2400 JK=1,ISTRIP
JSTRIP = JK
EAST = JSTRIP*MDIM
WEST = (JSTRIP-1)*MDIM+1
CALL INDATA
LF = 1
ILCOP = NLOW
DO 2400 KLN=1,2
C
DO 2000 KK=1,NSITE
KSIT = ISITE(KK,2)
YSIT = ISITE(KK,1)
ZSIT = ISITE(KK,3)+SENALT
C
DO 2000 LP=1,ILOOP
C *** TEST IFINISH FOR COMPLETION **
IEXP = (LP-1)*10+KK-1

```

```

      IFIN = AND(IFINISH(LP),2** (IEXP))
      IF (IFIN .NE. 0) GO TO 2000
      IF (LH .EG. 2) GO TO 400
C
      KS1 = LOWCEN(LP,2)
      IF (((KS1.GT.EAST) .AND. (KSIT.GT.EAST))
1     .OR. ((KS1.LT.WEST) .AND. (KSIT.LT.WEST))) GO TO 2000
C
C *** DETERMINE WESTERN MOST POINT OF PAIR **
      IF ((KSIT-KS1) .GE. 0) GO TO 300
C
C *** SWAP SENSOR AND NODE **
C
      XP = KS1
      YP = LOWCEN(LP,1)
      ZP = LOWCEN(LP,3)+VEHALT
      KS1 = KSIT
      XS1 = KSIT
      YS1 = YSIT
      ZS1 = ZSIT
      GO TO 525
C
300 XS1 = KS1
      YS1 = LOWCEN(LP,1)
      ZS1 = LOWCEN(LP,3)+VEHALT
      XP = KSIT
      YP = YSIT
      ZP = ZSIT
      GO TO 525
C
400 KS1 = HICEN(LP,2)
      IF (((KS1.GT.EAST) .AND. (KSIT.GT.EAST))
1     .OR. ((KS1.LT.WEST) .AND. (KSIT.LT.WEST))) GO TO 2000
C
C *** DETERMINE WESTERN MOST POINT OF PAIR **
      IF ((KSIT-KS1) .GE. 0) GO TO 410
C
C *** SWAP SENSOR AND NODE **
C
      XP = KS1
      YP = HICEN(LP,1)
      ZP = HICEN(LP,3)+VEHALT
      KS1 = KSIT
      XS1 = KSIT
      YS1 = YSIT
      ZS1 = ZSIT
      GO TO 525
C
410 XS1 = KS1
      YS1 = HICEN(LP,1)
      ZS1 = HICEN(LP,3)+VEHALT
      XP = KSIT

```



```

      YP = YSIT
      ZP = ZSIT
C
C *** CALCULATE TANGENT AND DISTANCE BETWEEN SENSOR/NODE **
C *** THE AZIMUTH ANGLE IS MEASURED FROM NORTH CLOCKWISE **
C
525 XSP = XP-XS1
    YSP = YP-YS1
    ZSP = ZP-ZS1
    DIS = SGRT(XSP**2 + YSP**2)
    IF(ZCURVE) DZ=0.5*DIS*(DIS/RE)
    TM = (ZSP-DZ)/(DIS*ZGRID)
    XSIN = XSP/DIS
    YCOS = YSP/DIS
    ZNORTH = .FALSE.
    ZSOUTH = .FALSE.
C
C *** DETERMINE STARTING INDICES AND MAP SHEET BOUNDARIES **
C
10 IF(XS1 .LT. WEST) GO TO 560
   NX = XS1-WEST
   YWEST = 0.0
   GO TO 570
560 NX = 0
   YWEST = YCOS*((WEST-XS1)/XSIN)
570 IF (ABS(XSIN).LE.SRTWH) GO TO 1150
C
C ***      EAST **
C
      IX = NX
      X = IX+WEST
      IDX = 1
1020 IX = IX+IDX
      X = X+RATE
      IF(IX .GT. MDIM) GO TO 2000
      R = (Y-XS1)/XSIN
      JY = R*YCOS+YS1
      NAR = (JY-1)/MDIM
      JY = JY-NAR*MDIM
      NAR = NAR+1
C
C *** TANGENT FOR ALL COMPASS DIRECTION **
C *** IF NAR OUTSIDE MAP SHEET - LOS EXIST **
C
1075 IF((NAR .LT. SOUTH) .OR. (NAR .GT. NORTH)) GO TO 1800
      Z = ICATA(JY,IX,NAR)
      IF(ZCURVE) DZ=0.5*R*(R/RE)
      T = (Z-ZS1-DZ)/(R*ZGRID)
      IF(T .LE. TM) GO TO 1090
      GO TO 1900
1090 IF(R .GE. RMAX) GO TO 1800
      IF(ZNORTH) GO TO 1130

```

IF(ZSCUTH) GO TO 1135
GO TO 1020

C

C *** NORTH ***

C

1130 Y = Y+DY
JY = JY+JDY
IF(JY .LE. MDIM) GO TO 1140
JY = 1
NAR = NAR+1
GO TO 1140

C

C *** SOUTH ***

C

1135 Y = Y+DY
JY = JY+JDY
IF(JY .GE. 1) GO TO 1140
JY = MDIM
NAR = NAR-1
1140 R = (Y-YS1)/YCOS
IX = R*XSIN+XS1
IF(IX .GT. MDIM) IX=IX-WEST+1
IF(IX .GT. MDIM) GO TO 2000
GO TO 1075

1150 IF(YCOS .GT. 0.0) GO TO 1160

C

C *** SOUTH ***

C

ZSOUTH = .TRUE.
JY = YS1+YWEST-RATE
NAR = (JY-1)/MDIM
JY = JY-NAR*MDIM
NAR = NAR+1
Y = YS1+YWEST-RATE
DY = -RATE
JDY = -1
GO TO 1140

C

C *** NORTH ***

C

1160 ZNORTH = .TRUE.
JY = YS1+YWEST
NAR = JY/MDIM
JY = JY+1-NAR*MDIM
NAR = NAR+1
Y = YS1+YWEST+RATE
DY = RATE
JDY = 1
GO TO 1140
1800 IF(LH .EG. 2) GO TO 1850
DETLO(LP) = DETLO(LP)+1.0
DISLO(LP) = DISLO(LP)+DIS

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